REPORT #
RRTAC 84-1

Land Surface Reclamation: A Review Of The International Literature Volume I

Heritage Fund

Alberta

LAND CONSERVATION AND
RECLAMATION COUNCIL
Reclamation Research
Technical Advisory Committee
ENVIRONMENT
Research Management Division

ALBERTA'S RECLAMATION RESEARCH PROGRAM

The regulation of surface disturbances in Alberta is the responsibility of the Land Conservation and Reclamation Council. The Council executive consists of a chairman from the Department of the Environment and two deputy chairmen from the Department of Energy and Natural Resources. Among other functions, the Council oversees programs for reclamation of abandoned disturbances and reclamation research. The reclamation research program was established to provide answers to the many practical questions which arise in reclamation. Funds for implementing both the operational and research programs are drawn from Alberta's Heritage Savings Trust Fund.

To assist in technical matters related to the development and administration of the research program the Council appointed the Reclamation Research Technical Advisory Committee (RRTAC). The Committee first met in March, 1978 and consists of eight members representing the Alberta Departments of Agriculture, Energy and Natural Resources, Environment and the Alberta Research Council. The Committee meets regularly to update research priorities, review solicited and unsolicited research proposals, arrange workshops and otherwise act as a referral and co-ordinating body for Reclamation Research.

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This Report may be cited as:

Sims, H.P., Powter, C.B., and Campbell, J.A.1984. Land Surface Reclamation: A review of the International Literature. Alberta Land Conservation and Reclamation Council Report #RRTAC 84-1. 2 Vols. 1549 pp.

Additional Copies may be obtained from:

Publication Services
Queen's Printer
11510 Kingsway Avenue
EDMONTON, Alberta
T5G 2Y5

LAND SURFACE RECLAMATION:

A REVIEW OF THE INTERNATIONAL LITERATURE

REPORT #RRTAC 84-1

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and Reclamation Council

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PREFACE

The Land Surface Reclamation Review was initiated by the Research Secretariat (now Research Management Division) as one of two monographs synthesizing literature on two priority problem areas of concern to Alberta Environment (the other being sulphur and sulphur emissions). It was decided in planning and preparation of the monograph that it should not be a typical literature review, having general statements substantiated only with a reference. The review contains details of methodology and experimental design, as well as data presented in tables and figures from the original reports so that readers are able to draw their own conclusions. Inclusion of such information added considerably to the magnitude of the task.

Since the enormity of the task precluded continuous updating of the Bibliography and the Review, a decision was made to exclude post-1980 references. While this cut-off date was necessary, unfortunately it excluded much of the more recent information from Alberta's research programs which, although preliminary, would have enhanced the report. However, our involvement with reclamation and reclamationists indicates that the information contained in the Review is still quite current.

This review might be considered as a useful reference for a university reclamation course. Although far from complete, the Review contains a scope of information not found elsewhere. While the document has dealt with the literature selectively, on the basis of relevance to Alberta, much of the information is nevertheless applicable to a much larger geographic region -- particularly Western Canada and the Western United States, and in combination with the complete bibliography, covers the international literature.

The presentation of tables and figures in the report necessitated that copyrights be obtained. Considerable effort was made to locate authors or publishers of all material. In a small percentage of cases we were unsuccessful and have taken the liberty of presenting that material, with references duly cited. Many thanks are due those who granted use of material without question. All tables

and figures from publications by Canada Departments of Agriculture, Environment, and Indian Affairs and Northern Development, Parks Canada, and the Canada Task Force on Northern Oil Development have been reproduced by permission of the Minister of Supplies and Services, Canada.

In the course of writing the Review it became obvious that the more recent literature was more sophisticated, focussed on more well-defined problem areas, and involved studies which were better designed. Reclamation has passed the trial-and-error stage and has assumed the stature of a true science. Still we have much to learn.

While the report primarily contains references to reclamation literature, there is a wealth of relevant information available in other more established fields, particularly ecology, agriculture, and forestry. There is an apparent lack of knowledge of silvicultural information and techniques displayed in reclamation literature. The literature contains very little information on reclamation/wildlife issues; this subject has gained some recognition only recently. The Review also does not deal with the economics of reclamation, largely because of the difficulties in obtaining current values, the problem of establishing to everyone's satisfaction just where reclamation begins and ends, and the problem of providing quantitative values for benefits such as wildlife, recreation, and aesthetics. The application of other sciences to reclamation, particularly modification of techniques to satisfy the unique conditions of mine spoil, is a challenge for the future.

This review is intended as an initial effort. The selection and interpretation of material in the Review is that of the authors. We are certainly under no misconception that readers will not disagree with our interpretations and conclusions. That is their right and that is why the data are presented in as complete form as possible.

The reader is advised to examine some of the more important documents in detail. A number of comprehensive handbooks on specific reclamation techniques are available and contain far more information

than could be effectively handled in this review. Such publications are highlighted in the text. Other publications such as existing summaries and books on reclamation (e.g. Rowe, J.E. 1979. Coal surface mining: Impacts of reclamation. Westview Press Inc. 490pp.) were either general and broad in scope, or were essentially research reviews in themselves, and did not lend themselves to summarization.

The reader should also contact the Chairman of the Reclamation Research Technical Advisory Committee, Government of Alberta, for a list of projects and publications related to that committee's research program. This information is highly relevant to Alberta but too recent or preliminary for inclusion in the Review.

The Review should be revised very soon. We recommend that the task begin immediately. We also recommend that the updated version focus on Alberta, or perhaps Western North America. We believe that the task should be considerably easier than our first effort and should result in a greatly improved report, which of course would be welcomed.

H.P. Sims
Senior Author

ACKNOWLEDGEMENTS

The list of people who have contributed time, funds and moral support to this project is so lengthy that we are sure we will miss one or two. We therefore thank collectively all those individuals and agencies who provided such help.

In particular special thanks are due to Dr. Koji Yamanaka and Mr. Ted Laidlaw for their patience and hard work in obtaining, processing, and summarizing information for the Review; to Ms. Laurie Skuba-Jackson who scoured provincial libraries and government and industry offices for references in the early days of the project; to Miss Dinah Van de Maat who meticulously logged each acquistion and guided it through the review process; to the staff of the Alberta Environment library, particularly Ms. Susan Moysa, Ms. Ione Hooper, Ms. July Thomas, and Ms. Bonnie Kendall for their assistance and extreme patience in obtaining elusive material; to Ms. Doreen Meisner, Ms. Christine McDonald, and Ms. Meliza Roberto for entering and continually revising this document on the word processor and to others in the Research Management Division secretarial and typing pool for their contributions; to Ms. Eleanor Hoffman for patiently typing the seemingly endless numbers of tables; to Mr. Jan Van Ens and Mr. Terry Zenith and their staff for drafting figures; to Ms. Jean Lowry who organized, edited, and massaged an uncoordinated mass of information into a final readable document; and to the numerous persons who contributed information and comments and reviewed and summarized papers and reports.

Special thanks are due to Mr. Ken Krogman, who wrote initial drafts of Chapters 8, 11, 15, 19, and 46 of the report and to Mr. Ray Chopiuk and Mr. Kenneth Chekerda who contributed subsection 5.2 of Chapter 5.

We are also greatly indebted to the Research Secretariat (now Research Management Division) of Alberta Environment, and to the Land Conservation and Reclamation Council for moral support and supplementary funding through the Heritage Savings Trust Fund. Finally we wish to thank the Reclamation Research Technical Advisory Committee, particularly Dr. Paul Ziemkiewicz, for their patience and moral support, without which the many obstacles encountered along the way could not have been overcome and the final objective achieved.

SECTION I

INTRODUCTION

1. BACKGROUND

1.1 PURPOSE AND OBJECTIVES OF THE STUDY

The economic boom of the previous decade resulted in unprecedented industrial development in Alberta. Exploration and extraction of oil, gas, and particularly coal deposits resulted in major land disturbance in the province and, combined with a growing concern for environmental protection, resulted in major efforts to formulate reclamation guidelines and legislation. It soon became obvious that the development, enforcement, and the achievement of compliance with regulations was a difficult task in light of the lack of information and answers in many problem areas.

Although much relevant information was available, most bibliographies were incomplete and references often inaccurate. Despite the apparent wealth of reports, the actual data base of research knowledge was an unknown in terms of scope, depth, accuracy, and knowledge gaps. Consequently, Alberta was on the verge of developing a research program without the benefit of a thorough review of work that had already been done or of where there was insufficient knowledge.

In 1976, the Research Secretariat, Alberta Environment, began a three phase project to establish an information base for reclamation and reclamation research in Alberta. The study had as its objectives:

1. to determine the state of the art of reclamation in Alberta (Phase I);
2. to compile a complete bibliography of references of confirmed accuracy (Phase II); and
3. to summarize and syntehsize all references relevant to Alberta in order to determine the international state of the art of reclamation relevant to the province (Phase III).

Phase I involved a survey of reclamation activities in the province (Sims et al. 1977) designed to determine the current status of reclamation, to identify the problem areas, and to identify persons actively involved in reclamation. Phase II produced a bibliography of

land surface reclamation (Sims and Powter 1982) which was international in scope and included references from 1970 to 1980, as well as some significant publications prior to that period. The bibliography contained a key word index and could be searched manually or by computer. Concurrent with the preparation of the bibliography, Phase III was initiated to review, summarize, and synthesize all reclamation research relevant to Alberta. This Review is the product of Phase III.

During the course of this study, an interdepartmental government program of reclamation research was developed in Alberta under the auspices of the Land Conservation and Reclamation Council of Alberta. An interdepartmental committee (the Reclamation Research Technical Advisory Committee) was charged with development and management of a government reclamation research program on behalf of the council.

In developing this program, the committee was forced to work within the constraints of time, expertise, and the knowledge base available to it in developing priorities and establishing programs in key areas. The following review will substantiate program direction in some key areas, provide new background information in other areas, identify knowledge gaps and research needs, and provide guidance for possible re-direction of the program.

1.2 DEFINITION OF RECLAMATION

In developing terms of references for its operation, the Reclamation Research Technical Advisory Committee defined reclamation and reclamation research as follows (extracted directly from the terms of reference of the committee):

Reclamation is broadly defined to include:

(a) The design and execution of a surface disturbance in such a manner to minimize the disturbance thereby enhancing its reclamation potential (toward a predetermined final land use);

(b) the handling of surficial material to ensure a surface conducive to the support of plant growth;

(c) the contouring of the surface to minimize hazardous conditions and ensure material stability and protect the surface against wind or water erosion;

(d) the preparation of the surface to a predetermined land use including the revegetation to appropriate introduced or native species to ensure biophysical productivity of the land (and creation of surface and groundwater regimes compatible with final land use); and

(e) where deemed the appropriate end land use, the self-sustained maintenance of the surface and vegetation without the assistance of man.

Definition of Reclamation Research:

(a) With respect to expenditure of the Heritage Trust Fund monies assigned to reclamation research, the Reclamation Research Technical Advisory Committee considers reclamation research to be any research directed toward the practical solution of problems arising from surface operations designated by Article 23(1) of The Land Surface Conservation and Reclamation Act.

(b) Reclamation research shall include research directed toward the practical solution of problems related to surface and subsurface waters arising from land disturbances designated by Article 23(1) of The Land Surface Conservation and Reclamation Act.

(c) Reclamation research shall include research directed toward the practical solution of problems arising from natural physical land disturbances as deemed necessary by the Committee.

(d) Reclamation research shall exclude research directed toward the proof of environmental impact of land disturbances but shall include research directed toward the investigation of alternatives to reclamation practices that have been shown to cause detrimental environmental impact.

(e) Reclamation research shall exclude research directed toward practical solution of problems arising from the impact of air-borne and waterborne effluents where (i) the situation can be alleviated by more economical direct corrective action taken at the source or (ii) where no corrective action will be taken at the source and information and technology are not available for lasting treatment of the damaged site.

(f) Reclamation research shall exclude research directed toward practical solution of problems arising from physical land disturbances which can be corrected by proper land management.

1.3 REFERENCES CITED

Sims, H.P. and C.B. Powter. 1982. Land Surface Reclamation: an International Bibliography. Alberta Land Conservation and Reclamation Council Report #RRTAC 82-1. 2 Volumes, 292 pp.

Sims, H.P., R.E. Leech, B.R. Hammond, L.S. Jackson and L.G. Brace. 1977. A survey of reclamation activities in the Province of Alberta. A report prepared for the Alberta Revegetation Research Co-ordinating Committee. Alberta Environment, Research Secretariat, Edmonton, Alberta. Report No. 2. 68 pp.

2. METHODOLOGY

2.1 METHODS USED FOR OBTAINING AND PROCESSING INFORMATION

In compiling the bibliography, references were obtained from more than ten data bases, from all bibliographies that could be obtained (our bibliography [Sims and Powter 1982] contains references to 44 such bibliographies), and from major libraries in the province. The actual reports and publications were then obtained wherever possible and the exact author, date, title, and source verified before inclusion in the bibliography. References that could not be obtained and verified (probably less than 3%) were excluded. All references were screened for their relevance to Alberta. While all were included in the bibliography, those relevant to Alberta were assigned a broad subject category (or categories).

When the bibliography was more than half complete, experts in the various category areas were selected to review and summarize the referenced literature. References were not completely summarized, but information relevant to Alberta was selectively extracted. For example, while a research project in the Eastern United States might deal with reclaiming highly acid mine spoil with species not adaptable to Alberta, site preparation techniques or cultural practices could possibly be of interest and were summarized. Contractors were carefully instructed in the procedure and supplied with two reference reports accompanied by example summaries. Selected references were identified for trial summarization and these summaries were checked by the senior author of this Review. Only when the contractor was quite familiar with the requirements of the final product were summaries of the entire set of reports completed.

A very comprehensive outline of the final Review, containing very specific subsections, was developed. As summaries were returned by broad category, they were reviewed and relevant subsections identified for each.

Writing of the final document was done entirely by the authors, with the exception of subsection 5.2 in Chapter 5, which is taken

directly from Chopiuk and Chekerda (1982: pp. 2-1 to 2-19) and preliminary drafts of Chapters 8, 11, 12, 15, 19 and 46 prepared by Mr. K. Krogman. Synthesis was done primarily from the summaries with constant verification of statements and data from the original reports.

Since it was impossible to maintain the collection and summarization of reports, the synthesis of information, and the preparation of the Review in current status, the Bibliography (Sims and Powter 1982) was published in late 1980. The Review therefore contains information up to and including 1980.

For consistency, all figures in the Review are presented in metric units. In situations where statistical differences or otherwise critical figures are reported, significant decimal places were retained. As a result some tables and figures may appear cluttered. In the majority of cases, figures were rounded off for clarity of presentation.

Tables and figures are presented only once, although some are referred to several times. This was done in the interests of economy of space and cost.

Scientific species names are used throughout the body of the text. In a few cases we could not be 100% certain of the proper scientific name when only common names were provided in publications. In such cases, the most common use of the non-scientific name was accepted. Species names in tables are presented as in the original papers.

Throughout the text, references to "the authors" concern the cited authors, not the authors of the Review.

2.2 REFERENCES CITED

Chopiuk, R.G. and K.J. Chekerda. 1981. Selective materials handling for strip mine reclamation in the Ardley coal zone. Coal Mining Research Centre, Mining Technology Division, Edmonton, Alberta. CMRC Report No. 82/12-T. Various pagings.

Sims, H.P. and C.B. Powter. 1982. Land Surface Reclamation: an International Bibliography. Alberta Land Conservation and Reclamation Council Report #RRTAC 82-1. 2 Volumes, 292 pp.

Sims, H.P., R.E. Leech, B.R. Hammond, L.S. Jackson and L.G. Brace. 1977. A survey of reclamation activities in the Province of Alberta. A report prepared for the Alberta Revegetation Research Co-ordinating Committee. Alberta Environment, Research Secretariat, Edmonton, Alberta. Report No. 2. 68 pp.

3. CURRENT STATUS OF OPERATIONAL RECLAMATION AND RESEARCH IN ALBERTA

3.1 OPERATIONAL RECLAMATION

Reclamation policies and regulations in Alberta are covered under the Land Conservation and Reclamation Act (Government of the Province of Alberta 1980, 1983) and related regulations. Reclamation requirements are spelled out in the "Guidelines for the Reclamation of Land in Alberta" (Alberta Environment, Land Conservation and Reclamation Council 1977). The guidelines are continually undergoing revision as new information becomes available.

Alberta is fortunate in not having a large backlog of prelegislation orphan mine spoils requiring attention. Development of major coal mining operations in the Plains, and Mountains and Foothills regions of the province and the mining of the Alberta Oil Sands began primarily in the last decade. Prior to that, disturbances were minimal. The province established a program in 1978, financed by the Heritage Savings Trust Fund, to reclaim all orphan spoil and as of 1983 this program is approximately 75% completed (L. Kryviak, Alberta Environment, Land Reclamation Division, personal communication).

There also are large acreages of disturbed land associated with pipelines, seismic lines, exploration roads, and other corridor activities in the province. However, most of these disturbances have been reclaimed following the specific operations or have revegetated naturally. Reclamation is generally a question of proper application of existing information, although there are localized, site-specific problems associated with such disturbances.

Industry is required to present evidence that disturbed areas can be reclaimed or to carry out research that will provide answers to problems by the time reclamation is to begin. Through a common interest, a cooperative program of research between government and industry has been developed for the coal and oil sand strip mine areas of Alberta.

3.2 MAJOR FORMS OF DISTURBANCE

In attempting to determine the total area of land disturbed in Alberta by activities such as mining, energy exploration and development, and highway construction, the authors found no one source which collates such information. It is felt that such information should be available for the entire province on an annual basis to facilitate reclamation planning.

Disturbance in the "Green Area" of the province has been documented in a recent study by Hardy Associates (1978) Ltd. (1982a) in consultation with the Alberta Forest Service. This study looked at maps and aerial photographs taken from 1950 to 1975 and digitized area measurements of:

1. seismic lines;
2. oil and gas roads and wellsites;
3. powerlines and pipelines;
4. gas plant sites and infrastructure;
5. coal exploration, coal mines, and infrastructure;
6. tar sands plant sites and infrastructure;
7. multipurpose facility rights of way; and
8. miscellaneous areas including industrial camp sites and airstrips.

Data from these measurements were used to produce a report outlining the area disturbed by each activity in 10 forests of the Green Area.

3.2.1 Surface Mining

One of Alberta's primary natural resources is coal. There are an estimated 81 x 10^9 t of potentially recoverable coal in Alberta (Webb 1982). Slightly more than 90 percent of this coal is found in the Plains region; that is, in that area of the province extending southward from Lesser Slave Lake and eastward from the foothills of the Rocky Mountains. Webb noted that nearly 1 260 000 ha of land in Alberta are underlain by coal fields and isolated deposits; 526 000 ha (42 %) of this total are arable (Class 1 to 4) soils, and 85 819 ha (7 %) are suitable for

improved pasture (Class 5). In contrast to these estimates, Thompson (1981) indicated that almost 70% of coal fields are underlain by Class 1 to 4 land and 21% are under Class 1 and 2 land. About 7.4×10^9 t of coal (10.3 percent of the ultimately recoverable coal in the Plains region) can feasibly be recovered by strip mining (Webb 1982). Potentially, 155 520 ha (1554 km^2) of largely agricultural land in Alberta could be affected by strip mining. Thompson (1981) estimated that by the year 2004, more than 28 000 ha will be disturbed at any one time in the Plains region bringing the total area disturbed between 1975 and 2004 to 69 000 ha. Mining infrastructure would double this figure.

To date, only a small fraction of the 155 520 ha have been disturbed by coal mining. Existing and already approved coal leases will affect 12 182 ha of land (Webb 1982). As of mid-1981, over 99 percent of the coal used for thermal power production in Alberta was obtained from five surface mines, the Diplomat Mine operated by Forestburg Collieries Ltd., and the Highvale, Roselyn, Vesta, and Whitewood mines operated by Manalta Coal Ltd. Within the past year the production of thermal coal from the Diplomat Mine has been replaced by coal from the Paintearth Mine. Coal from the Diplomat Mine is now used primarily for domestic purposes. Based on data provided by the Land Reclamation Division of Alberta Environment the total area disturbed at these five sites, as of August 1981, was 3149 ha, 879 ha of which have been disturbed since 1976.

Coal mine and tar sands plant disturbance were estimated by Hardy Associates (1978) Ltd. (1982a) at 10 839 ha or 3.4% of the total disturbed portion of the Green Area. This total represents only 0.03% of the Green Area. Disturbance of this type occurred in two of the ten provincial forests (Athabasca -- 5808 ha; Edson -- 5016 ha) and removed or destroyed an estimated 550 000 m^3 of commercial timber.

Due to the small number of mines in the original study, Hardy Associates (1978) Ltd. (1982b) was asked to survey six coal mines either active or at the proposal stage in the Green Area.

The area of these mines was measured and an estimate of the potential timber loss calculated. The data in Table 3.1 are an

Table 3.1. Area of potential disturbance of six coal mines in the Green Area of Alberta.

Mine	Disturbance (ha)
Union Oil - Obed Marsh	6 638
Gregg River	3 645
Cardinal River Coal	2 218
McIntyre Mines	5 587
Coal Valley	5 259
Denison Coalspur	5 322
Total	28 670

Source: Hardy Associates (1978) Ltd. (1982b).

indication of the potential size of disturbance at the six mines and do not represent current levels of disturbance.

3.2.2 Corridors

By far the greatest amount of disturbance in the Green Area of Alberta is from geophysical exploration (seismic lines), amounting to 219 071 ha or 70% of the total disturbed area (Figure 3.1). The amount of disturbance in the 10 provincial forests ranged from 0.14% (8107 ha) in the Athabasca Forest to 1.98% (27 547 ha) in the Whitecourt Forest.

Smaller disturbances were caused by multipurpose rights of way at 31 360 ha (10% of disturbed area), and powerlines and pipelines at 15 258 ha (4.8% of disturbed area).

Assumptions were made as to the width of linear disturbances to facilitate calculation of area disturbed. Seismic lines were assumed to have a standard width of 7.6 m while other rights of way were assigned a width of 20.1 m.

Webb (1982:1a, 1b) has recently collated information on the impacts of linear developments on Alberta's agricultural land base. His findings are summarised here:

"In 1981 there were...[155 794 km] of power lines in Alberta, which can be broken down as follows: transmission lines (over 60 kV)...[15 593 km], subtransmission and distribution lines (60 kV or less)...[61 422 km], rural electrification area lines...[67 736 km], and utility-owned farm lines...[11 041 km]....Data on the length of power lines within the White and Yellow areas of Alberta (the primary agricultural areas) is not readily available. Nevertheless, the rural electrification area lines and utility-owned farm lines, and long lengths of transmission lines, are found in the White and Yellow areas of Alberta....There are approximately ...[178 277 km] of pipeline in Alberta which are under the jurisdiction of the ERCB....Another...[1931 km] of pipeline which move, or will be moving hydrocarbons out of the province are under the jurisdiction of the National Energy Board and the Northern Pipeline Agency. The total length of pipeline in Alberta is therefore approximately...[180 208 km]....

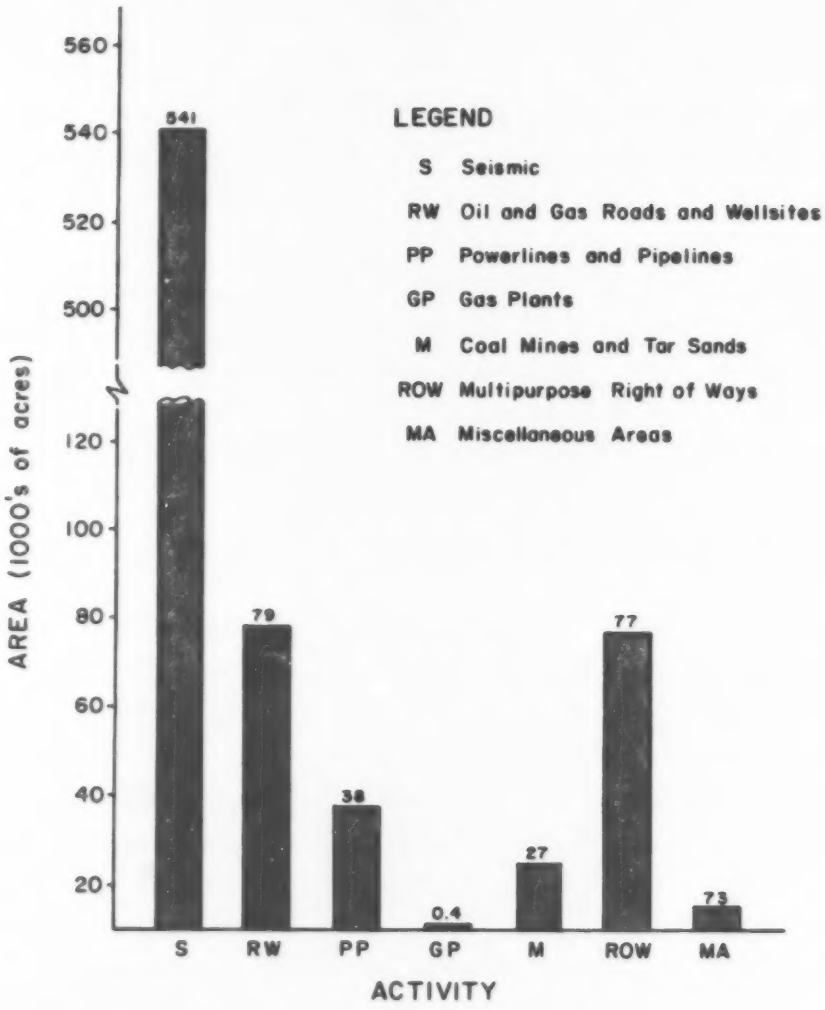

Figure 3.1. Total area (10^3 acres) disturbed by each disturbance activity (all forests and cover types combined) in the Green Area, Alberta.

Source: Hardy Associates (1978) Ltd. (1982b).

"Land is disturbed when pipelines are installed, but the resultant harm to the land base seems to be minimal."

Data obtained from the 1980/81 Annual Report of Alberta Transportation (1983) indicate that approximately 310 km of new roadways outside urban areas were constructed during that fiscal year. In addition to this disturbance over 2 800 000 m^3 of gravel and 457 977 m^3 of sand were excavated. Webb (1982) found that the area disturbed by road construction in the White and Yellow areas of the province between 1976 and 1980 totalled 10 156 ha, including 3916 ha for new roads and 5658 ha for road widening operations.

3.2.3 Well Sites

The study by Hardy Associates (1978) Ltd. (1982a) found that developed oil and gas roads and well sites were the second greatest source of disturbance in the Green Area, at 13 022 ha, or 10.2% of the total disturbed area. Secondary disturbances such as miscellaneous oil and gas developed areas and gas plants disturbed 5368 ha (1.7%) and 181 ha (0.06%), respectively.

Using a similar 1.6 ha size for wells, Webb (1982) estimated that 44 064 ha of agricultural land (White and Yellow areas) are currently occupied by active wells, 38 880 ha have been abandoned and not reclaimed, and 27 994 ha have been abandoned and reclaimed. Webb noted that while this area of land may actually be disturbed, much of the land is returned to the farmer as soon as the well is producing or capped. Only the area occupied by the access road and the well head is lost for any length of time.

3.2.4 Other Disturbances

Thermal power generating plants take up a substantial amount of land for the power plants and associated facilities, notably the cooling ponds. For example, while the Wabamun and Sundance plants occupy 381 ha, the cooling ponds occupy 1239 ha (Webb 1982). Webb noted that approximately 0.4 ha of cooling pond is needed for each megawatt of power. Thus projections by the Energy Resources Conservation Board that

28 more 375 mW plants will be required by the year 2005 indicate a further potential loss of 5557 ha.

Webb (1982) has also noted that accidental spills of hydrocarbons and salts associated with oil and gas drilling operations have been small considering the number of wells drilled; however, the effects of these spills may be quite severe. Webb noted that in 1979 there were approximately 650 oil and salt water spills; 110 of these were in excess of 1260 barrels (200 214 L).

3.3 RECLAMATION RESEARCH

The reclamation research program developed by the Reclamation Research Technical Advisory Committee in cooperation with industry, deals with reclamation on a regional basis. Programs have been established in the Plains and North-east (Oil Sands) regions and a third is currently being developed for the Mountains and Foothills region. For specific details of the program the reader is referred to the annual report for the program (Ziemkiewicz 1983). In order to effectively integrate information from the following Review with the research program, subjects are discussed wherever possible on a regional basis. Information from outside Alberta was incorporated into the most relevant region (e.g., information from Arctic sites was included primarily in the Mountains and Foothills region and sometimes in the North-east region; information from the China Clay region of Great Britain was included in the discussion of the North-east Oil Sands region).

3.4 REFERENCES CITED

Alberta Environment, Land Conservation and Reclamation Council. 1977. Guidelines for the reclamation of land in Alberta. Prepared by the Land Conservation and Reclamation Council, Alberta Environment and Alberta Energy and Natural Resources. Various pagings.

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Hardy Associates (1978) Ltd. 1982b. Area and volumes of timber within six coal development permit areas in the Green Area of Alberta. Prepared for Alberta Energy and Natural Resources by Hardy Associates (1978) Ltd., Calgary, Alberta. Various pagings.

Thompson, P.S. 1981. Non-agricultural land use. IN: J.T. Harapiak (Chairman). Proceedings of the Eighteenth Annual Soil Science Workshop Featuring a Symposium on Land Degradation; Edmonton, Alberta; February 24-25, 1981. Alberta Soil and Feed Testing Laboratory, Edmonton, Alberta. pp. 365-392.

Webb, C. 1982. Impacts of linear developments, resource extraction, and industry on the Agricultural land base. Report No. ECA82-17/1B25. Environment Council of Alberta, Edmonton, Alberta. 87 pp.

Ziemkiewicz, P.F. 1983. The Alberta Government reclamation research program, 1982. Alberta Land Conservation and Reclamation Council Alberta Environment, Edmonton, Alberta. 25 pp.

4. FACTORS AFFECTING RECLAMATION IN ALBERTA

Alberta occupies an area of 661 188 m^2, including approximately 16 796 km^2 of water, bordered by the 49th parallel in the south and the 60th parallel in the north.

Elevation in the province ranges from less than 304.8 m above sea level in the northeast (Athabasca Delta Plain area), to over 3500 m in the Rocky Mountains (Mt. Columbia 3747 m). The majority of the area sits between the 304.8 and 914.4 m levels.

Both latitude and altitude affect reclamation efforts through their effects on climate, growing season, vegetation, soils, and current land use.

With increasing altitude and latitude the frost free period, temperature, and growing season all decrease which reduces the amount of time for soil reconstruction, seeding, and plant establishment. Photoperiod, on the other hand, increases with increasing latitude; thus, while the growing season decreases the amount of sunlight for plant growth actually increases.

Increasing altitude and latitude result in lower soil temperature and moisture levels which in turn result in less microbial activity and poorer nutrient cycling. In mountainous areas there may be little or no topsoil available to cover spoils thus affecting the choice of species.

Geography and climate help determine the current land use which, in turn, determines the reclamation goals for a given region. Thus land is returned primarily to agriculture in the Plains, and to recreation, wildlife, and forestry in the Mountains and Foothills and in the North-east region.

The choice of species for reclamation work in the three regions must, therefore, be based on considerations of end land use, climatic limitations, and soils limitations.

4.1 CLIMATE

Strong and Leggat (1981) have classified the province into 12 ecoregions based on vegetation, soils, and climate. They noted that while climate data alone could not be used to distinguish the zones, they provided excellent information for adjusting tenuous or uncertain boundaries.

Three major climatic regimes or ecoprovinces occur within Alberta: (1) Prairie, (2) Cordilleran and (3) Boreal. The interaction of these major climatic regimes influences the heat and moisture availability characteristics of the 12 ecoregions in Alberta. These major climatic zones are influenced by factors such as latitude, elevation, land area, and storm tracks.

The following is a summary of the climates of the major ecoprovinces in Alberta taken from the paper by Strong and Leggat (1981:43). Further detailed descriptions of the climate in each ecoregion may be found in their paper. Table 4.1 presents a summary of the climatic data available for each ecoregion. Strong and Leggat have provided a list of the climate stations that contributed data for each region in their report.

"The Prairie Ecoprovince (Ecoregions 1, 2, 3, and 4) is characterized by a late summer moisture deficit which promotes herbaceous vegetation growth and restricts arboreal species....The amount of available moisture for plant growth increases from Ecoregion 1 to 4, inclusive. This increased availability is only partially the result of increased precipitation. Temperatures tend to decrease from Ecoregion 1 to 4 as a response to the east to west increase in elevation and the northward increase in latitude. This plays a role in reducing evapotranspiration, and moisture availability is increased.

"Ecoregions 1, 2, and 3 receive maximum precipitation in June; however, Ecoregion 4 has a July maximum....[allowing] an increase in woody species, particularly aspen.

"The Cordilleran Ecoprovince (Ecoregions 5, 6, and 7) is dominated primarily by the effects of vertical rather than horizontal climatic changes. With rapidly increasing elevations, temperatures

Table 4.1. Climatic data summary for the ecoregions of Alberta.

Ecoregion	May to September: Mean Temperature °C			Growing Degree Days above 5°C			Frost Free Period			Number of Days 0°C or less			Total Precipitation (mm)			Percent of Annual	No. of days Precipitation 0.2 mm or more			Climatic Moisture Deficit		
	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.		Mean	Max.	Min.	Mean	Max.	Min.
Short Grass	15.0	16.0	14.5	1570	1750	1380	115	125	100	10	15	5	210	250	170	64	35	40	25	-300	-350	-360
Mixed Grass	14.5	15.0	13.5	1440	1610	1290	110	125	85	15	25	10	260	290	200	65	40	45	30	-240	-300	-200
Fescue Grass	13.5	13.5	11.0	1310	1330	950	90	110	25	20	50	15	350	370	230	61	40	55	30	-170	-200	-160
Aspen Parkland	13.0	15.0	10.0	1260	1480	850	95	125	35	20	45	10	300	400	250	67	50	60	35	-160	-220	-30
Montane	11.5	13.0	10.5	1030	1120	920	75	85	55	30	40	20	270	390	110	50	50	60	35	-160	-240	-40
Subalpine	9.5	10.5	8.0	810[3]	930	710	15[2]	15	15	60[4]	65	50	320	430	180	51	50[4]	60	50	-110[2]	-140	-80
Alpine	6.5	7.5	4.0	ND	ND	ND	ND	ND	ND	10	10	10	360	430	270	48	ND	ND	ND	ND	ND	ND
Boreal Mixedwood	12.0	14.0	10.5	1150	1310	970	85	120	50	20	30	10	300	440	200	72	55	65	35	-150	-270	-100
Boreal Foothills	11.5	12.5	10.0	1080	1140	1020	80	105	50	25	60	10	370	450	230	66	60	65	50	-70[4]	-90	-20
Boreal Uplands	10.0	11.5	8.5	740[1]	740	740	75	105	20	30	65	15	300	470	250	62	60	70	55	-20[2]	-30	-10
Boreal Northlands	11.0	12.0	10.0	1050[3]	1080	1010	85[3]	105	65	25	30	25	250	340	180	55	50[4]	55	45	ND	ND	ND
Boreal Subarctic	10.0[3]	10.0	9.5	ND	ND	ND	ND	ND	ND	ND	ND	ND	300[1]	300	300	ND	ND	ND	ND	ND	ND	ND

Ecoregion	December to February: Mean Temperatures °C			No. days with Chinooks			Winter Season: No. days with continuous snow cover			Maximum depth of snow cover (cm)			October to April: Total Precipitation			Annual: Temperature °C			Total Precipitation			No. days Precipitation 0.2 mm or more			Hours of Bright sunshine		
	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.	Min.
Short Grass	-10.5	-8.0	-13.5	20	35	10	95[2]	100	85	25[2]	30	25	120	150	80	4.0	5.5	2.5	340	380	260	70	90	45	2310[2]	2460	2170
Mixed Grass	-10.0	-6.0	-15.0	20	35	5	105[2]	130	80	35[2]	45	25	140	190	90	4.0	5.5	1.0	400	470	300	75	105	55	2390[1]	2390	2390
Fescue Grass	-8.0	-6.0	-12.5	30	35	15	95[2]	100	90	30[2]	35	25	230	500	120	3.5	5.0	2.0	520	870	370	90	115	70	2210[1]	2210	2210
Aspen Parkland	-12.5	-7.0	-16.0	10	30	5	135[4]	150	120	40[2]	55	30	160	400	100	2.0	3.5	0.0	450	710	390	95	130	60	2210	2360	2090
Montane	-7.5	-6.5	-9.5	20	30	10	145[2]	155	130	50[2]	50	50	300	480	170	3.0	4.0	2.5	560	810	280	105	130	80	1740[1]	1740	1740
Subalpine	-9.0	-7.5	-12.0	15[2]	30	5	ND	ND	ND	ND	ND	ND	400	830	170	1.5	2.5	0.0	720	1210	350	120	135	100	ND	ND	ND
Alpine	-14.0[1]	-14.0	-14.0	ND	ND	ND	ND	ND	ND	ND	ND	ND	400	590	240	-4.5[1]	-4.5	-4.5	730	970	570	ND	ND	ND	ND	ND	ND
Boreal Mixedwood	-15.5	-11.5	-23.0	10	20	<5	150	155	140	50	55	45	170	250	120	0.5	3.0	-3.0	440	520	350	105	135	60	2050[4]	2340	1840
Boreal Foothills	-10.0	-8.0	-12.5	20[4]	25	10	145[1]	145	145	45[1]	45	45	240	350	170	2.0	3.0	1.0	570	670	510	110[4]	125	90	2000[1]	2000	2000
Boreal Uplands	-10.5	-8.5	-12.5	10[1]	10	10	ND	ND	ND	ND	ND	ND	220	300	160	1.0	1.5	-0.5	580	740	440	105[2]	110	110	ND	ND	ND
Boreal Northlands	-24.0[3]	-23.5	-24.5	ND	ND	ND	185[1]	185	185	55[1]	55	55	160[3]	170	140	-3.5	-3.5	-4.0	340[3]	450	350	120[2]	130	115	2040[1]	2040	2040
Boreal Subarctic	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Source: Strong and Leggat (1981:4-5)

[a] Superscripts indicate the number of stations when less than 5.

[b] Sources: Alberta Forest Service, 1978, Atmospheric Environment Service 1975a, b; Acton, 1975; Hamerlak and Randall 1972; Longley 1967; and Potter 1965.

decrease and precipitation increases. Winter precipitation is much greater than that in other ecoprovinces. Associated with the complex topography are orographic precipitation, escape from cold dense arctic air masses, increased influence of maritime air masses, increased winds, high variability of chinooks, and strong temperature gradients. All of these factors play an important role in the ecology of the Cordilleran Ecoprovince. The variety of landscapes combined with the numerous climatic conditions produces ecological diversity. The microclimatic conditions may be created by changes in just one variable such as aspect.

"The Montane Ecoregion occurs at the lower elevations of this ecoprovince on some of the warmest winter sites in Alberta. These warm winter sites are created by warm air being channeled from British Columbia into Alberta through major east-west valleys, and by protection from cold Arctic outbreaks.

"The Subalpine Ecoregion is less affected by factors influencing the Montane. Summers are [characterized by]....cooler temperatures (mean May to September 10.5°C), high frost frequency, and short growing season....

"The principles outlined for the Subalpine generally hold true for the Alpine Ecoregion, the difference being one of degree....The Alpine is not modified by chinooks due to its high elevational location, but is strongly influenced by winds. Winds cause desiccation through high evapotranspiration and physical damage to exposed vegetation....

"...The climate of... [the Boreal Ecoprovince] is controlled by the high latitude and a general decrease in elevation from south to north. Due to latitude this is a low energy environment. This tends to increase moisture availability for the vegetation.

"Two distinctive climatic pathways have developed in reponse to the topographic and locational modification of the Boreal Ecoprovince climate. The first pathway involves Ecoregions 9 and 10, and is related to increased elevation in the Rocky Mountains. The Cordilleran influence is significant within this portion of the Boreal Ecoprovince. Increased precipitation, decreased summer temperatures, and increased winter temperatures are among the most salient features. In the Boreal Uplands

the summer temperatures average less than 10.5°C which results in a decreased composition of deciduous trees and a dominance of conifers. This is similar to Ecoregion 6. The Boreal Foothills Ecoregion is warmer....while Boreal Mixedwood vegetation represents even warmer summer climatic conditions....

"The second pathway is composed of a latitudinal and elevational sequence from the Boreal Mixedwood through the Boreal Northlands to the Boreal Subarctic Ecoregion. The Boreal Northlands is moister than the Mixedwood due to increased latitude and decreased temperatures. This area has a mean summer temperature near 11.0°C....

"In summary, the ecoregions of Alberta are all broad ecotones. Grasslands grade from the most arid to the more moist. Ecoregion 4, the Aspen Parkland, is a transition zone between the grasslands and the forested ecoregions. Within the forested ecoregions the trend is for a gradation from deciduous to coniferous forest. Aspen is the principal deciduous species and only appears to be dominant where the mean May to September temperatures is above 10.5°C. Ecoregions 6, 7, 10, and 12 are below this temperature while Ecoregion 11 is near or at the 10.5°C isotherm....Under the most severe climatic conditions forest gives way to alpine or subarctic vegetation (Ecoregions 7 and 12)."

In Table 4.1, Strong and Leggat (1981) have also shown the ranges and means of the frost free period and growing degree days for the 12 ecoregions. As can be seen from these data, the alpine and subalpine regions have the shortest growing season while the short grass and mixed grass prairies have the longest.

Brocke (1977) has produced a map (Figure 4.1) of the agro-climatic areas of Alberta to be used as a general guide in determining the range of crops that, as a result of a combination of climatic factors, can be satisfactorily grown in each area. According to Brocke, the best growing regions correspond roughly to the Aspen Parkland and Mixed Grass ecoregions of Strong and Leggat (1981). The Shortgrass ecoregion is limited by moisture while the Fescue Grass ecoregion is limited by temperature. Most other regions are limited by both temperature and precipitation.

Figure 4.1. Agro-climatic areas of Alberta.

Legend: This map delineates areas that have, on the long-term average, similar climatic characteristics for cropping purposes. It is an attempt to provide a general guide in determining the range of crops that, as a result of a combination of climatic factors, can be satisfactorily grown in each area. It must be emphasized that climate is only one of the physical factors that influence the range of crops grown: there are others, particularly soil type and topographic features.
THE LINES DIVIDING THE AREAS ARE USUALLY BROAD TRANSITION BELTS: RARELY IS THERE A SHARP CHANGE IN CLIMATE FROM ONE AREA TO ANOTHER. The area boundaries are delineated by broken lines to indicate that they are subject to change when additional data becomes available. Local topographical features and proximity to lakes and muskegs can cause local conditions: cold "frost pockets"; exceptionally good air drainage with longer than normal frost-free periods; warm belts; areas with heavy dew formation; and areas with more or less precipitation than the average for the larger area. These conditions may differ significantly from the average for the area but cannot be shown on a map of this scale. The frost-free data quoted in the area descriptions are long-term averages. It is recognized that throughout most of Alberta the average frost-free period since about 1950 has been significantly longer than for the period of record before that date. For the purpose of this map, however, the 1950-1965 period has been considered as an anomaly and not as a trend. The map was compiled in collaboration with members of the Alberta Soil Survey using information taken from: (1) publications of the Meteorological Service of Canada; (2) Climates of Canada for agriculture, CLI Report No. 3 by Chapman and Brown of the Ontario Research Foundation; (3) The frost-free period in Alberta by R.W. Longley of the University of Alberta; (4) data and observations gathered by members of the Alberta Soil Survey; and (5) observations by grain elevator agents and federal and provincial field personnel. Recognition is also given for suggestions and data provided by Dr. A. Leahey, G.W. Robertson, and J. Day, of the Canada Department of Agriculture, Ottawa. The map was initially compiled to assist the Soil Survey to determine the capability of Alberta soils for agricultural use. The Arabic number designation of the areas indicates relative capability: 1 being top or best. The subscript A (aridity) indicates that moisture is the limiting factor. The subscript H (heat) indicates that such factors as summer heat units, frost-free periods, and days between peak summer rainfall and first fall frost, are limiting factors.

Figure 4.1 LEGEND, continued

Areas where the amount of precipitation has usually been adequate and the frost-free period long enough to permit the growing of all the dryland crops that are typical to the Prairie Region of Western Canada. The frost-free period in these areas has averaged over 90 days and the annual precipitation has averaged 16 to 18 inches.

2A Areas where the amount of precipitation, in approximately 50 percent of the years, has been a limiting factor to crop growth. The Frost-free period has usually been long enough for wheat to mature without frost damage. In the 2A(H) area south of Lethbridge there is some frost hazard.

3A Areas where the amount of rain has usually been a severe limiting factor to crop growth; a wheat-fallow rotation is practiced to the virtual exclusion of all other rotations. The annual precipitation has averaged 12 inches. The frost-free period has averaged slightly over 100 days in the northern portion of the area and over 115 days in the south central portion. Wheat is rarely damaged by frost and sweet corn can be grown, under irrigation, in the southern portion.

2H Areas where the amount of precipitation has usually been adequate but where wheat has suffered some frost damage in approximately 30 percent of the years. The frost-free period has averaged between 75 and 90 days.

3H Areas where the amount of precipitation has usually been adequate but where it is not considered practical to grow wheat because of the frequency of damaging frosts. In the areas south of Latitude 55°N the average annual precipitation has averaged 17 to 19 inches. Going north from Latitude 55°N there is a gradual drop in precipitation and at Fort Vermilion the annual average is between 12 and 13 inches.*

5H Areas where the amount of precipitation has usually been adequate but where the average frost-free period has been so short (generally less than 60 days) that it is not practical to grow cereal crops; that is, hay crops are all that are recommended.*

UNC Mountain complex and Precambrian Shield. There is little to no agricultural potential in these areas.

*The portion of the province north of Latitude 58°N has an average annual precipitation of less than 14 inches. In most of this area rainfall, or lack of rainfall, may be an additional limiting factor to crop growth in a significant number of years. Therefore the 3 and 5 areas that, in general, lie north of Latitude 58°N are given the limiting subscript A in addition to H: i.e., 3H(A) and 5H(A).

Source: Adapted from Brocke (1977)

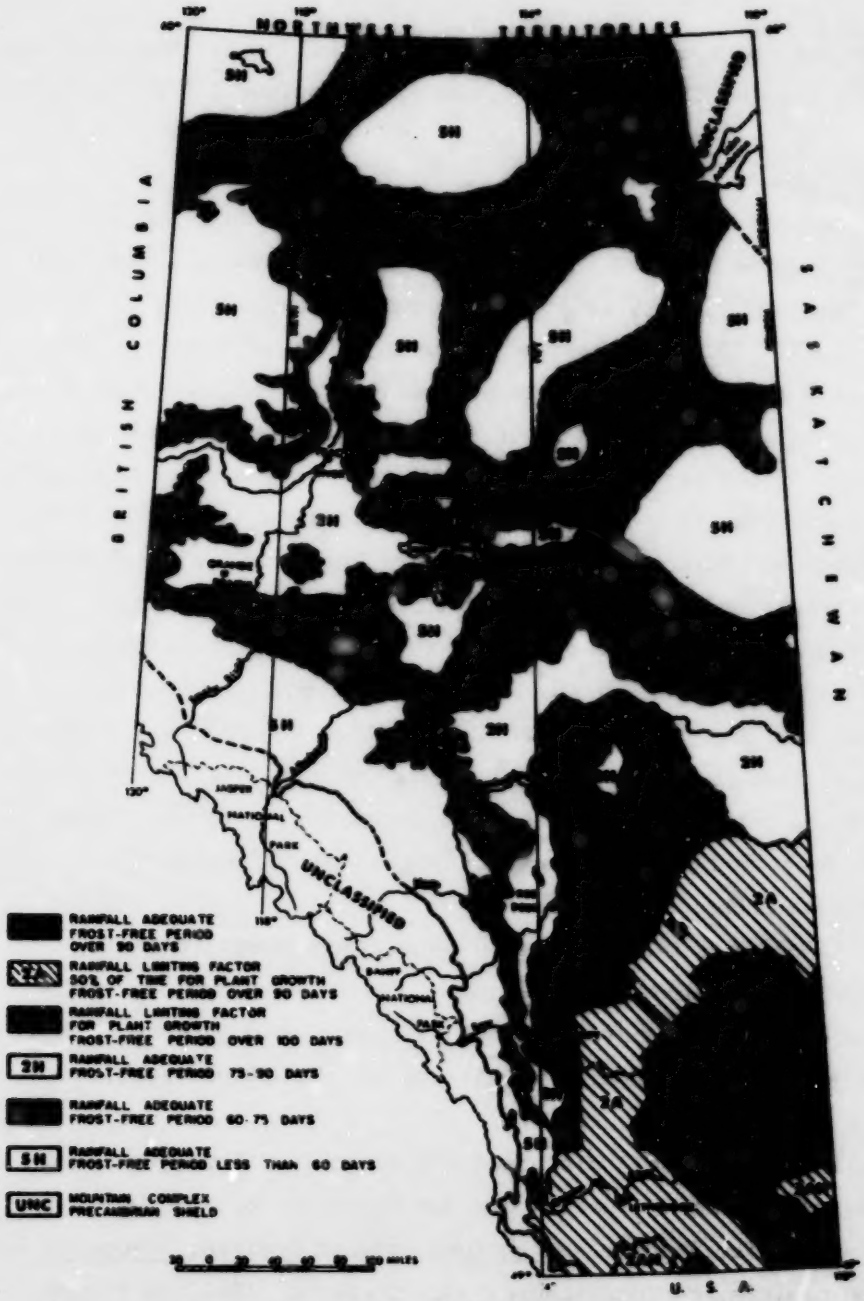

NORTHWEST TERRITORIES
BRITISH COLUMBIA
SASKATCHEWAN
U. S. A.
UNCLASSIFIED
RAINFALL ADEQUATE FROST-FREE PERIOD OVER 90 DAYS
RAINFALL LIMITING FACTOR 50% OF TIME FOR PLANT GROWTH FROST-FREE PERIOD OVER 90 DAYS
RAINFALL LIMITING FACTOR FOR PLANT GROWTH FROST-FREE PERIOD OVER 100 DAYS
2H RAINFALL ADEQUATE FROST-FREE PERIOD 75-90 DAYS
RAINFALL ADEQUATE FROST-FREE PERIOD 60-75 DAYS
SH RAINFALL ADEQUATE FROST-FREE PERIOD LESS THAN 60 DAYS
UNC MOUNTAIN COMPLEX PRECAMBRIAN SHIELD

Figure 4.1. Agro-climatic areas of Alberta.

Source: Adapted from Brocke (1977)

Other important sources of climatic information for the Province of Alberta are: Longley (1972a, b) and Powell and MacIver (1977, 1978).

4.2 VEGETATION

An integrated approach has also been used to describe the vegetation zones in the province by Strong and Leggat (1981), Looman and Best (1979), Rowe (1972), Moss (1955), and Coupland (1950, 1961). As noted by Moss (1955:494), the province "...is a region of vegetational transition zones. Here, two great plant formations, steppe and forest, come together, having east-west and north-south ecotones, as well as outliers, one within the other. Here also, is the meeting ground of east (Atlantic) and west (Pacific) floras, or, more precisely, of boreal and Cordilleran elements. Moreover, in the north of the Province, transition from boreal to arctic begins." Because of this incredible diversity it is not possible to adopt one single reclamation program for the entire province. Each ecoregion will require specific reclamation measures.

Looman and Best (1979), in an introduction to their key to the flora of the prairies, gave very general ecological descriptions of four main regions in the province (prairies, parklands, boreal forest, Rocky Mountains) and four "exceptional areas" (Cypress Hills, Peace River district, sand dune areas, saline areas).

Moss (1955) described six main vegetation zones (prairie, parkland, poplar association, boreal forest, Cordilleran forest, and alpine) which were further subdivided into 25 common associations. Each of these associations were discussed in terms of the common species present and the ecology of the area.

Coupland (1950, 1961) discussed the ecology of four grassland communities in the Northern Great Plains (mixed prairie, Stipa - Bouteloua; true prairie, Stipa - Sporobolus; palouse prairie, Agropyron - Festuca; fescue prairie, Festuca scabrella). Coupland (1961) in Figure 4.2 shows the mixed prairie and fescue prairie occurring in Alberta.

Rowe (1972) delineated five main forested regions in Alberta in addition to the tundra and grassland areas. The boreal forest occupies the greatest area in the province and is divided into three types:

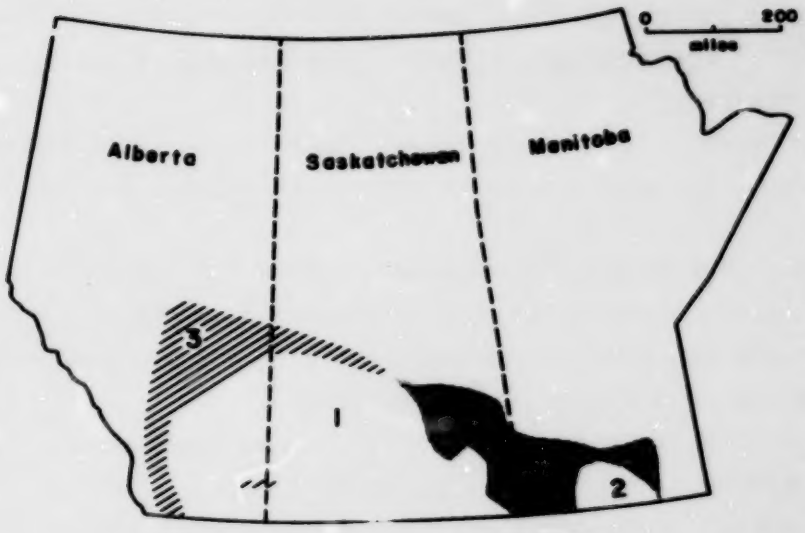


Figure 4.2. Outline map showing distribution of natural grasslands east of the Rocky Mountains in Canada; 1--Mixed Prairie, 2--True Prairie, 3--Fescue Prairie, 4--Communities of Mixed Prairie and Fescue Prairie alternate.

Source: Coupland (1961)

(1) predominantly forest--Picea glauca and P. mariana, Abies balsamea, Pinus banksiana, Betula papyrifera, Populus tremuloides; (2) forest and barren-- Picea glaua, P. mariana, and Larix laricina; and (3) forest and grass-- Populus tremuloides, Salix spp. The subalpine forest (Picea engelmanni, Abies lasiocarpa, Pinus contorta) is next largest, followed by the montane forest (Pseudotsuga menziesii, Pinus contorta, P. ponderosa, and Populus tremuloides).

More recently, Strong and Leggat (1981) derived 12 ecoregions for the province. The areal extent of the various regions is shown in Table 4.2.

Figures 4.3 through 4.14 show the locations of the 12 ecoregions and indicate the most common plant species found in each region. A note on the most common soil type is given on the figures along with a general description of the current land use in the region.

In addition to the above references, several keys are available for the vegetation of the province. The following is a partial list of the most useful keys, along with a brief summary of each.

1. Best, Looman and Campbell (1971). Contains a description of grass parts and a key to grasses with line drawings and botanical descriptions.
2. Looman and Best (1979). Includes a general description of vegetation zones in the prairies as well as a key to the vegetation with botanical descriptions.
3. Cormack (1967). Contains pictures of species with layman's descriptions of plants.
4. Moss (1959). Contains a key to the species and botanical descriptions.

Figure 4.3. Location of Short Grass Ecoregion.

Characteristics: Ecosystem distribution along an environmental gradient. Modal ecosystem delineated by the box.

DRY/WARM — WET/COOL

Grama-Wheat Grass Well drained Solonetzic and Solonetzic Brown Chernozem	Grama-Spear Grass (Dry periods) Moderately well drained Brown Chernozem	Spear-Grama Grass (Wet periods) Moderately well drained Brown Chernozem	Spear-Grama-Wheat Grass Moderately well drained Dark Brown Chernozem	Spear-Wheat Grass Moderately well drained Dark Brown Chernozem (Loamy soils) / Wheat-June Grass Moderately well to imperfectly drained Brown and Dark Brown Chernozem (Clayey soils)	Buckbrush-Wolf Willow Imperfectly to moderately well drained Chernozem, Regosol, Brunisol	Poplar, Willow, Birch Imperfect to poorly drained Regosol, Gleysol

Present Uses: Presently, the Short Grass Ecoregion is utilized for cattle production on native pasture, and crop production. Sugarbeets, alfalfa, and vegetable crops are important products from irrigated land, although wheat, oats, and barley are important on both irrigated and unirrigated lands.

Source: Strong and Legget (1981)

Figure 4.4. Location of Mixed Grass Ecoregion.

Characteristics: Ecosystem distribution along an environmental gradient. Modal ecosystem delineated by the box.

DRY/WARM — WET/COOL

Grama-Spear Grass (Dry periods) Well to rapidly drained Brown Chernozem	Spear-Grama Grass (Wet periods) Well to rapidly drained Brown Chernozem	Spear-Grama-Wheat Grass Moderately well drained Dark Brown Chernozem	Spear-Wheat Grass Moderately well drained Dark Brown Chernozem / Wheat-June Grass Moderately well to imperfectly drained Dark Brown Chernozem	Rough Fescue Moderately well drained Black Chernozem	Buckbrush-Wolf Willow Imperfect to moderately well drained Chernozem, Brunisol, Regosol	Poplar, Willow, Birch Imperfect to poorly drained Regosol, Gleysol

Present Uses: Irrigation and dry land farming are the major uses of the Mixed Grass Ecoregion. Small grain is the most common crop produced. Cattle grazing occurs where irrigation water is not available or the topography is unsuitable for tilled cropping.

Source: Strong and Legget (1981)

Figure 4.3. Location of the Short Grass Ecoregion.
Source: Strong and Leggat (1981).

Figure 4.4. Location of the Mixed Grass Ecoregion.
Source: Strong and Leggat (1981).

Figure 4.5. Location of Fescue Grass Ecoregion.

Characteristics: Ecosystem distribution along an environmental gradient. Modal ecosystem delineated by the box.

DRY/WARM					WET/COOL
Spear-Wheat Grass Well drained Dark Brown Chernozem	Rough Fescue-Parry Oatgrass Moderately well drained Black Chernozem	Buckbrush-Wolf Willow Moderately well drained Black Chernozem	Rose-Saskatoon Moderately well to imperfectly drained Brunisol, Chernozem	Aspen, Willow Imperfect Regosol, Brunisol Chernozem	

Present Uses: Land suitable for tilled cropping is used for grain production while grazing dominates the native grasslands. Native forage production is approximately twice that of the Mixed Grass Ecoregion.

Source: Strong and Leggat (1981)

Figure 4.6. Location of Aspen Parkland Ecoregion.

Characteristics: Ecosystem distribution along an environmental gradient. Modal ecosystem delineated by the box.

DRY/WARM

	Groveland Subregion						
Spear-Wheat Grass Well drained Dark Brown Chernozem	Rough Fescue Well to moderately well drained Black and Dark Brown Chernozem	Buckbrush-Wolf Willow Moderately well drained Chernozem	Rose-Saskatoon Moderately well drained Chernozem	Aspen Moderately well to imperfectly drained Black Chernozem	Aspen-Spruce Imperfect to poorly drained Gleysol	Willow Imperfectly poorly drained Gleysol	Sedges Poorly drained Regosol

				Aspen Subregion			
Spear-Wheat Grass Well drained Dark Brown Chernozem	Rough Fescue Well drained Black Chernozem	Buckbrush-Wolf Willow Moderately well drained Black Chernozem	Rose-Saskatoon Moderately well drained Chernozem	Aspen Moderately well drained Black Chernozem	Aspen-Spruce Imperfect to moderately well drained Black Chernozem	Willow Imperfectly to poorly drained Gleysol	Sedges Poorly drained Regosol

Present Uses: Presently, the Aspen Parkland represents one of the most productive agricultural zones in Alberta. Barley, wheat, rapeseed, and oats are the most commonly tilled crops. Beef cattle grazing occurs in the foothills and on rough topography.

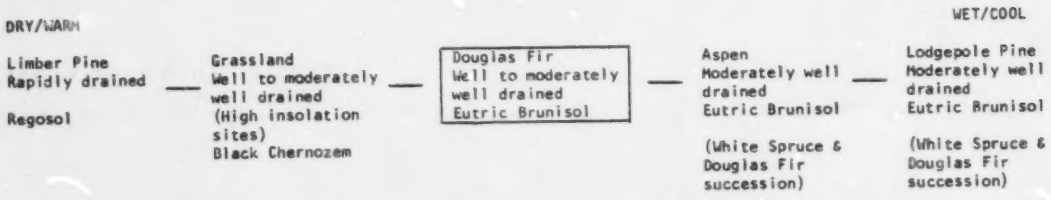
Source: Strong and Leggat (1981)

Figure 4.5. Location of the Fescue Grass Ecoregion.
Source: Strong and Leggat (1981).

Figure 4.6. Location of the Aspen Parkland Ecoregion.
Source: Strong and Leggat (1981).

Figure 4.7. Location of Montane Ecoregion.

Characteristics: Ecosystem distribution along an environmental gradient. Modal ecosystem delineated by the box.

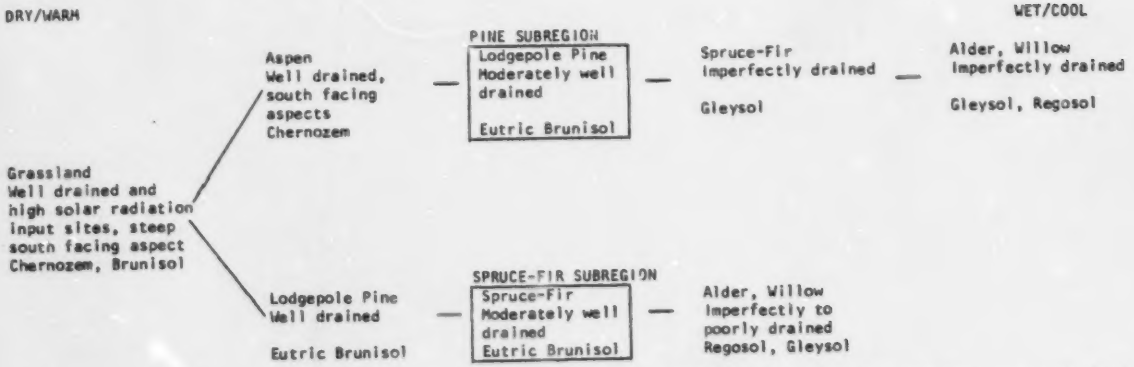


Present Uses: The majority of the Montane Ecoregion landscape consists of steep and rough topography. As a result activities such as recreation and domestic grazing are common. This area may form an important winter habitat area for large ungulates.

Source: Strong and Leggat (1981)

Figure 4.8. Location of Subalpine Ecoregion.

Characteristics: Ecosystem distribution along an environmental gradient. Modal ecosystem delineated by the box.



Present Uses: Watershed management and protection, forest production, National Parks, and recreation are amongst the land uses that can be observed in the Subalpine Ecoregion. The area is also important as habitat for wildlife species.

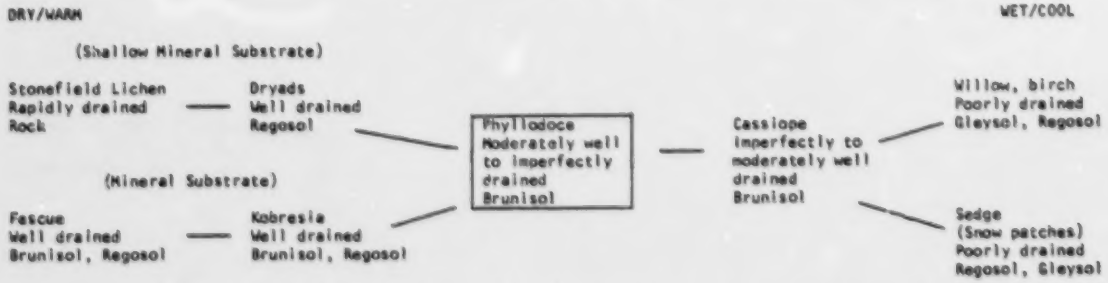
Source: Strong and Leggat (1981)

Figure 4.7. Location of the Montane Ecoregion.
Source: Strong and Leggat (1981).

Figure 4.8. Location of the Subalpine Ecoregion.
Source: Strong and Leggat (1981).

Figure 4.9. Location of Alpine Ecoregion.

Characteristics: Ecosystem distribution along an environmental gradient. Modal ecosystem delineated by the box.

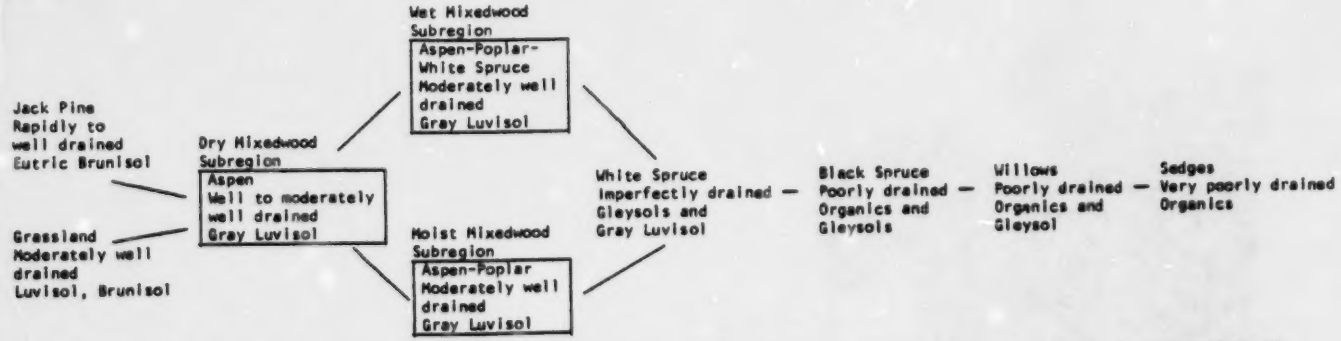


Present Uses: The Alpine Ecoregion is probably one of the most fragile and unique ecological systems in Alberta. Watershed management and protection, recreation activities, and wildlife habitat are important concerns and uses of this area.

Source: Strong and Leggat (1981)

Figure 4.10. Location of Boreal Mixedwood Ecoregion.

Characteristics: Ecosystem distribution along an environmental gradient. Modal ecosystem delineated by the box.



Present Uses: The uses occurring within the Boreal Mixedwood are generally more intensive than extensive. Agriculture is common along the southern fringes of the Mixedwood boundary and in the Peace River Valley. The Dry Mixedwood Subregion contains more than 85% of the land under cultivation within Ecoregion 8. In the past, this subregion has often been classified, or considered, part of the Aspen Parkland. In terms of crop yields, this subregion has much lower yields than the Aspen Parkland Ecoregion which is probably due to lower temperatures, decreased solar radiation associated with latitude, frost damage, soils, and adverse climate at time of harvest. Forestry activities are scattered throughout Ecoregion 8. Recreational activities are commonly limited to localities where access is possible.

Source: Strong and Leggat (1981)

Figure 4.9. Location of the Alpine Ecoregion.
Source: Strong and Leggat (1981).

Figure 4.10. Location of the Boreal Mixedwood Ecoregion.
Source: Strong and Leggat (1981).

Figure 4.11. Location of Boreal Foothills Ecoregion.

Characteristics: Ecosystem distribution along an environmental gradient. Modal ecosystem delineated by the box.

DRY/WARM — WET/COOL

Open Lodgepole Pine Well drained Brunisol (White Spruce succession)	-	Aspen-Poplar-Lodgepole Pine Well to moderately drained Gray Luvisol (White Spruce succession)	-	Lodgepole Pine Imperfectly drained Gleysol (Black and White Spruce succession)	-	Black Spruce Poorly drained Organic, Gleysol (Black Spruce succession)	-	Willows Very poorly drained Organic, Gleysol	-	Sedges Very poorly drained Organic, Gleysol

Present Uses: The eastern edge of this area is used for agriculture (forage production, grazing, and tilled cropping). Topography and climate preclude these uses elsewhere in the ecoregion. Tree harvesting occurs throughout the area. This ecoregion has some of Alberta's most productive forest.

Source: Strong and Leggat (1981)

Figure 4.12. Location of the Boreal Uplands Ecoregion.

Characteristics: Ecosystem distribution along an environmental gradient. Modal ecosystem delineated by the box.

DRY/WARM — WET/COOL

Open Lodgepole Pine Bearberry, Juniper Rapidly to well drained Brunisol	-	Lodgepole Pine Well to moderately well drained Luvisol, Brunisol (White Spruce succession)	-	Lodgepole Pine Imperfectly drained Gleysol, Luvisol, Brunisol (White and Black Spruce succession)	-	Black Spruce Poorly drained Gleysol and Organic (Black Spruce succession)	-	Birch/Sedge Very poorly drained Organic (Black Spruce succession)

Present Uses: The Boreal Uplands is used primarily for wood fiber production, although watershed management is an important consideration. Other activities such as agriculture are severely restricted due to the cool and short summers.

Source: Strong and Leggat (1981)

Figure 4.11. Location of the Boreal Foothills Ecoregion.
Source: Strong and Leggat (1981).

Figure 4.12. Location of the Boreal Uplands Ecoregion.
Source: Strong and Leggat (1981).

Figure 4.13. Location of Boreal Northlands Ecoregion.

Characteristics: Ecosystem distribution along an environmental gradient. Modal ecosystem delineated by the box.

DRY/WARM — COOL/WET

Jack Pine Rapidly to well drained Dystric Brunisol	Aspen - Well drained - Brunisol	**Aspen/Spruce Well to moderately well drained Gray Luvisol**	White and Black Spruce - Imperfectly drained - Gleysol	Black Spruce - Poorly drained - Gleysol, Organic, Cryosol	Willows - Poorly drained - Organic, Gleysol Cryosol	Sedges - Very poorly drained Organic Cryosol

Present Uses: Forestry, hunting, and trapping activities are amongst the uses occurring within this area. A large portion of the ecoregion is contained within Wood Buffalo National Park.

Source: Strong and Leggat (1981)

Figure 4.14. Location of Boreal Subarctic Ecoregion.

Characteristics: Ecosystem distribution along an environmental gradient. Modal ecosystem delineated by the box.

DRY/WARM — WET/COOL

Pine, Aspen, Poplar Well drained Brunisol, Luvisol	Black Spruce, White Spruce - Moderately well to poorly drained - Organic	**Open Black Spruce/ Labrador Tea/Sphagnum/Lichen Poorly drained to moderately well Organic, Cryosol**	Labrador Tea-Birch/Sphagnum - Poorly to very poorly drained Organic, Cryosol

Present Uses: Uses of this ecoregion are limited by the permafrost, cool summers, and poor access. The most important land use occurring is probably wildlife habitat.

Source: Strong and Leggat (1981)

Figure 4.13. Location of the Boreal Northlands Ecoregion.

Source: Strong and Leggat (1981).

Figure 4.14. Location of the Boreal Subarctic Ecoregion.

Source: Strong and Leggat (1981).

Table 4.2. Approximate areal extent of ecoregions in Alberta.

Ecoregion	Ecoregion Number	Percent Area	km^2
Short Grass	1	7.1	46 926
Mixed Grass	2	4.7	31 063
Fescue Grass	3	2.2	14 403
Aspen Parkland	4	11.1	73 268
Montane	5	0.5	3 538
Subalpine	6	3.5	23 133
Alpine	7	2.8	18 506
Boreal Mixedwood	8	43.2	286 611
Boreal Foothills	9	9.6	63 362
Boreal Uplands	10	4.1	27 098
Boreal Northlands	11	7.2	47 588
Boreal Subarctic	12	4.0	26 437
TOTAL		100.0	660 933

Source: Adapted from Strong and Leggat (1981).

5. Porsild (1974). Designed for use primarily in Jasper, Banff and Waterton Lakes National Park; includes species pictures and botanical descriptions.
6. Rydberg (1969). Covers Colorado, Utah, Wyoming, Idaho, Montana, Saskatchewan, and Alberta as well as parts of Nebraska, South and North Dakota, and British Columbia; includes a key to the species and botanical descriptions.

4.3 PHYSIOGRAPHIC REGIONS

The physiographic region and division concepts have been integrated into the Soil Survey at large scales (e.g., at the Order, Great Group, and occasionally Subgroup level). Thus the Soil Survey Inventory is related to the physiographic classification system (Clayton et al. 1977). The inventory relates a map unit (e.g., C2-26 in Clayton et al.) or specific spatial area to soils, physiography, soil climate, topography, soil parent material, vegetation and land use (Table 4.3).

As part of the national soil survey, soil climatic classes have been developed. These are based primarily on temperature and moisture regimes. The soil temperature and moisture regimes for Alberta are mapped in detail by Clayton et al. The soil temperature classification represents an integration of air and soil temperature regimes and their seasonal variations. This relationship is shown graphically in Figure 4.15 for the Cryoboreal cold subhumid climate of 3.1f. The large areal extent of this soil climate class can be seen on the map in Clayton et al. The soil temperature classification also includes measures of the growing season, including degree days and thermal period (Table 4.4).

The moisture regimes include a seasonal assessment of moisture deficit and supply, including precipitation, irrigation, and groundwater recharge as shown in Figure 4.16 for the semi-arid class. The spatial extent of this moisture class can also be seen on the map in Clayton et al.

Integration of the soil survey into the biophysical environment has been accomplished with a physiography bias. The main emphasis has

Table 4.3. Example of relationship of soil survey data to physiographic classification system.

Map unit											
	Soil subgroups			Physiography		Physical characteristics					Reference
Symbol Canadian (FAO/UNESCO)	1 Dominant >40% area 2 Subdominant >20% area 3 Significant inclusions 10 to 20%	Phase	Area sq mi (km^2)	1 Region 2 Division 3 Local subdivision 4 Range of elevation, m	Soil climate Temperature class Moisture subclass	Topography and Landform	Texture and character of parent material	Vegetation and Land use	Geographic grid reference	1 Source 2 Reliability
C2 26 (Lo2-2a)	1 Orthic Gray Luvisol 3 Fibrisol		26 836	1 Interior Plains 2 Alberta Plateau 3 Little Smoky River Valley 4 610 to 910	3.1 Cryoboreal cold a Humid	Undulating to gently rolling glacial till plain	Loamy, slightly calcareous till and lake-modified till	Field crops and forage, productive mixed upland forest, and nonproductive coniferous lowland forest	87, 8	1 Alberta 2 Soil survey

Source: Adapted from Clayton et al. (1977)

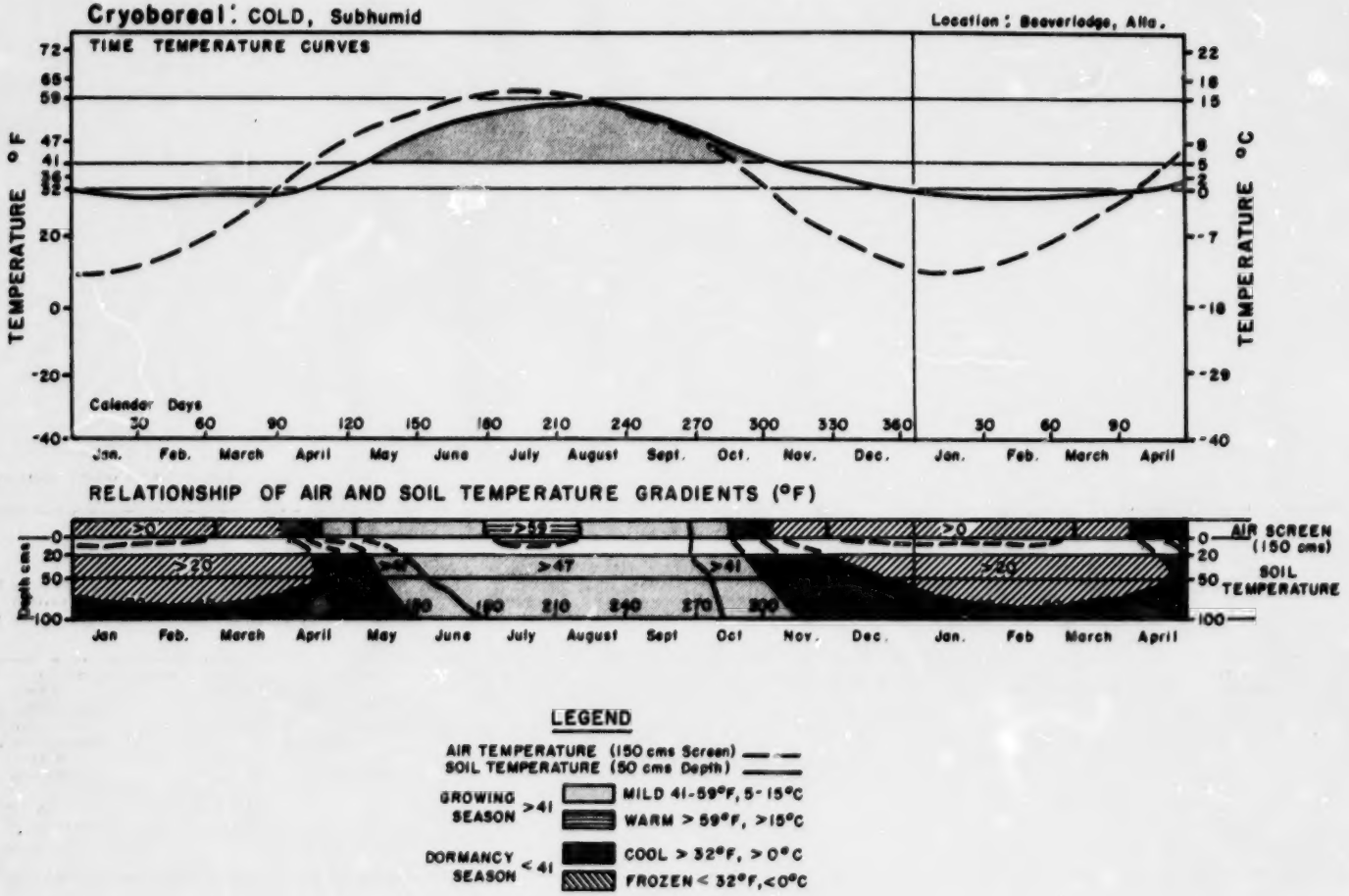

Cryoboreal: COLD, Subhumid
Location: Beaverlodge, Alta.
TIME TEMPERATURE CURVES
TEMPERATURE °F
TEMPERATURE °C
Calendar Days
Jan. Feb. March April May June July August Sept. Oct. Nov. Dec. Jan. Feb. March April
RELATIONSHIP OF AIR AND SOIL TEMPERATURE GRADIENTS (°F)
Depth cms
AIR SCREEN (150 cms)
SOIL TEMPERATURE
LEGEND
AIR TEMPERATURE (150 cms Screen)
SOIL TEMPERATURE (50 cms Depth)
GROWING SEASON >41
MILD 41-59°F, 5-15°C
WARM > 59°F, >15°C
DORMANCY SEASON < 41
COOL > 32°F, > 0°C
FROZEN < 32°F, <0°C

Figure 4.15. Environmental soil temperature regime for Beaverlodge, Alberta.

Source: Clayton et al. (1977)

Table 4.4. Example characteristics of Cryoboreal soil temperature classes. Generalized characteristics of temperature classes used for the soil climate maps of Canada and North America.

COLD TO MODERATELY COLD

[a] Mean annual soil temperature 36 to < 47°F (2 to < 8°C)
[a] Mean summer soil temperature 47 to < 59°F (8 to < 15°C)
[b] Growing season ≥ 41°F (≥ 5°C); 120 to 220 days
[b] Growing season degree days > 41°F, 1000 to < 2250 (≥ 5°C, 555 to < 1250)
[c] Thermal period ≥ 59°F (≥ 15°C), no significant days
[c] Thermal period degree-days > 59°F, < 60 (≥ 15°C, < 33)

Soils with aquic regimes may remain frozen for portions of the growing season. Organic soils having discontinuous or localized permafrost should be classified in 2.

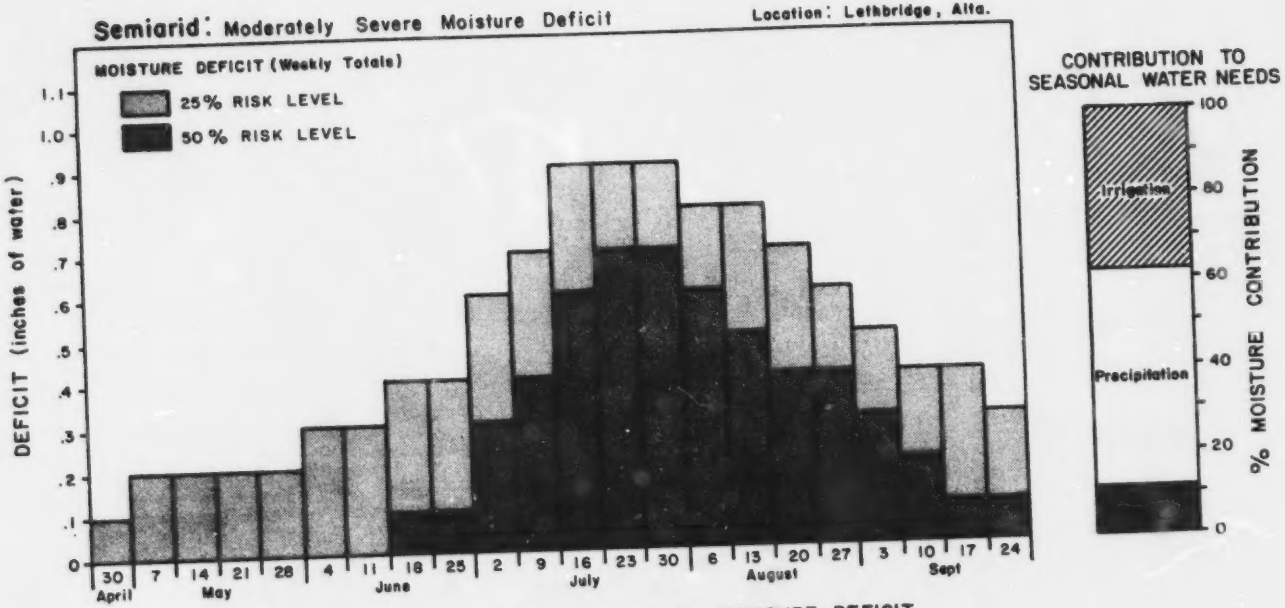
COLD

[b] Growing season ≥ 41°F (≥5°C), 120 to 180 days
[b] Growing season degree-days ≥ 41°F, 1000 to < 2000 (≥5°C, 555 to < 110)

MODERATELY COLD

[b] Growing season ≥ 41° F (≥ 5° C), < 220 days
[b] Growing season degree-days > 41°F, 2000 to < 2250 (≥5°C, 1110 to < 1250)

Source: Adapted from Clayton et al. (1977).
[a] Primary classifier for class; in accordance with criteria established for the FAO/VNESCO Soil Climate Map of North America, measured at a depth of 50 cm.
[b] Secondary classifier for Soil Climate Map of Canada.
[c] Supplementary information.



DISTRIBUTION OF SEASONAL MOISTURE DEFICIT

	ANNUAL	SEASONAL
PRECIPITATION	16.7	9.4
POTENTIAL EVAPOTRANSPIRATION	26.9	21.9

POTENTIAL WATER USE		18.7
IRRIGATION REQUIREMENT	25% RISK LEVEL	9.0
	50% RISK LEVEL	7.3

Figure 4.16. Unsaturated soil moisture regime for Lethbridge, Alberta.

Source: Clayton et al. (1977)

been on the physical nature of materials such as surficial geology, geomorphology, soils, and the morphology or landforms, and climate. Land use and vegetation components of the survey have traditionally been oriented towards agriculture as the soil survey has been closely allied with, if not part of the federal and provincial Agriculture departments.

The first significant broadening of this bias in Canadian Soil Survey came when the mapping of land capability for agriculture was significantly extended to cover other uses including recreation, forestry, wildlife, and most recently urban or housing uses such as suitability for septic systems.

One example of ecological land classification is the recent work on wetlands in Canada by the Wetland Working Group of the Canada Committee on Ecological Land Classification (Canada. Department of Environment 1981; Rubec and Pollett 1980). A large percentage of these wetlands are peat or organic soils. Although recently it is changing in many traditional soil surveys, organic soils are not differentiated or mapped in detail and they may, in fact, become almost non-mapping units. Only one detailed map o organic soils exists in Canada, specifically for southwestern Manitoba (Mills, Hopkins and Smith 1977). Thus very little is known about organic soils. Almost all of Canada's organic soils are in a virgin state and most are in remote northern areas. Figure 4.17 shows the prevalence of wetlands in Alberta, especially in northern Alberta. A preliminary, simple classification of wetland types, equivalent to ecoregions in scale, has begun (Figure 4.18).

There will always be biophysical classifications developed from time to time, external to the two main systems presently in wide use in Canada. Many are developed for a specific purpose with a narrowly defined application where the generalized systems are inadequate. For example, a horticultural climate or frost hazard mapping was done some time ago by Agriculture Canada.

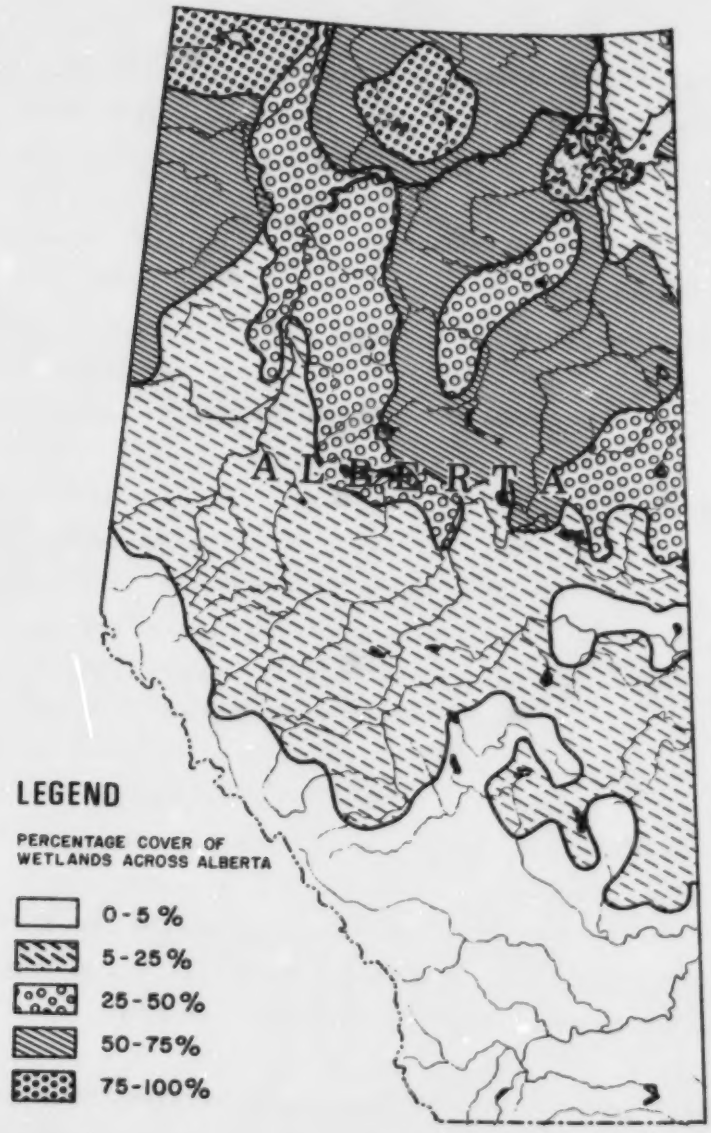


Figure 4.17. Percentage cover of wetlands across Alberta.

Source: Canada Department of Environment (1981)

Figure 4.18. Wetlands regions in Alberta.

Explanation of legend:

BMc Continental Mid-Boreal Wetlands

Flat bogs and basin bogs are common, often associated with fens. Occasionally, somewhat elevated, flat-topped bog plateaus occur in larger fens. Locally, marshes can be found along lakeshores. The common maximum peat thickness is about 5 m.

BMt Transitional Mid-Boreal Wetlands

This area is transitional between the Prairie to the south and the Boreal region. Basin fens and bogs, thicket swamps and marshes occupy depressions in about equal proportions. Flat fens and floating fens occur along drainageways and lakeshores. Peat accumulation is in the order of 3 m on bogs, but less in fens, and is minimal in swamps and marshes.

BHc Continental High Boreal Wetlands

Peat plateaus, palsas, and veneer bogs are common but fens are of relatively minor importance. Permafrost distribution is more widespread and the amount of collapsing decreases in the northern portions. The active layer ranges from 40 cm to 60 cm in the north to 1 to 2 m in the southern fringe. Veneer bogs, common in the northern portions, are characterized by active layers of varying depths and a discontinuous occurrence of permafrost. Coniferous and thicket swamps are locally common.

PCa Aspen Parkland Continental Prairie Wetlands

Semi-permanent ponds and freshwater marshes usually support an encircling shrubby or treed border. Small depressions are often occupied by grass and shrub meadows. Saline marshes may border larger lakes. There is a limited development of well-humidified peat, usually less than 50 cm thick.

Mx MOUNTAIN COMPLEX

Areas identified as mountain complexes are not wetland regions, but complexes of wetland regions due to vertical climatic zonation imposed by the mountainous terrain. The kind of wetland developing at suitable locations will depend on the latitude and elevation of the location. Thus in a given area, bogs typical of the mid-boreal region may occur in the lowest valleys but at higher elevations the wetlands will resemble those found in subarctic or arctic areas. Because of such complex vertical zonation, the wetland regions are not described here and are not shown on the map.

SI LOW SUBARCTIC Wetland Region

Common wetlands are peat pastures, and patterned (ribbed or string) and horizontal fens. Palsas are frequent in the areas generally east of Nelson River in Manitoba, but far more restricted farther west. The climate is characterized by cold winters, and moderately cool summers. The precipitation is low in the west, but it is considerably higher east of Nelson River.

Permafrost occurs under peat pastures and palsas, but not under fens. The active layer is about 60 cm at its maximum development. The common maximum thickness of peat is 3-4 m.

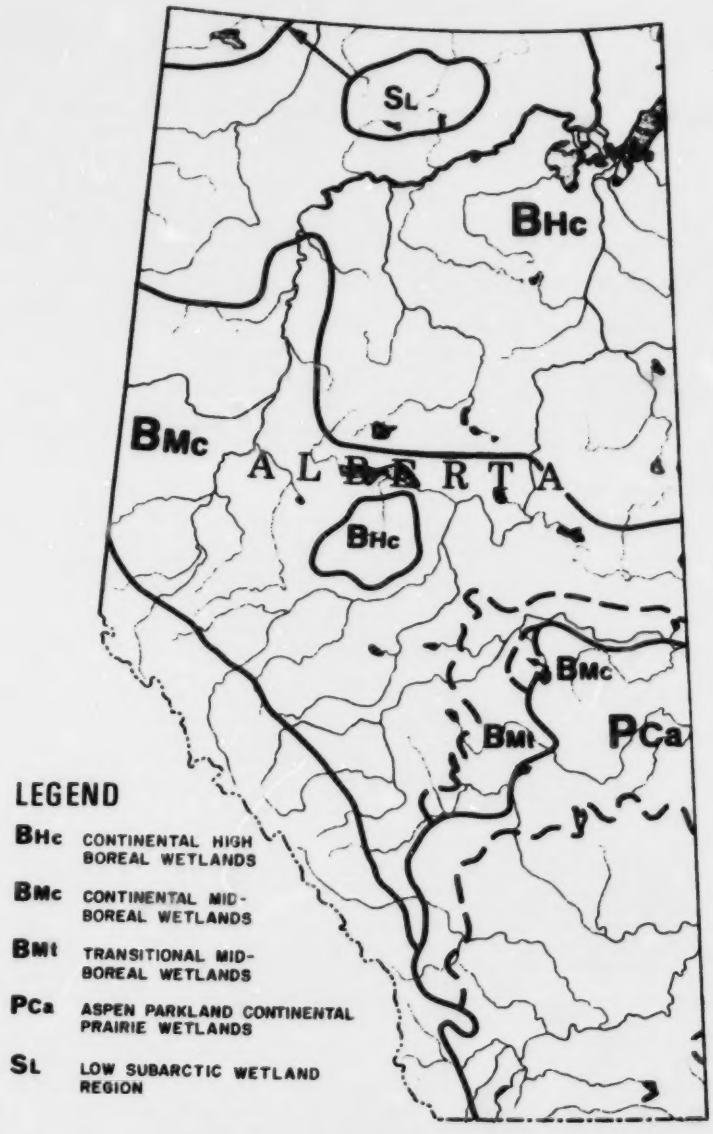


Figure 4.18. Wetlands regions in Alberta.

Source: Canada Department of Environment (1981)

4.3.1 Characteristics of Mapping and Classification Units

The physiographic regions, sub-divisions and soil subgroups in Alberta are described below. The information is taken from Soils of Canada, Volume 1 (Clayton et al. 1977).

4.3.1.1 The Canadian Shield. The Shield is represented in only a very small portion of the northeast corner of Alberta. Known as the Churchill Geological Province, it includes two physiographic divisions: (1) the Athabasca Sandstone Plain, and (2) the Kazan Upland. The latter dominates the Churchill Province in area and is characterized by extensive glacial deposits.

4.3.1.2 The Cordilleran Region. Along the western edge of Alberta lies the easternmost portions of the Cordilleran Region. The southern Rocky Mountains and part of the Rocky Mountain Foothills physiographic divisions are found within Alberta. Through the former runs the southern Rocky Mountain Trench oriented in a northwest to southwest direction. The trench is a large, fault controlled depression modified by erosion and glaciation. Flowing through the trench are many rivers including the Athabasca River in the north, the Saskatchewan River in the middle and the Bow River further south. This physiographic region roughly corresponds to the Mountains and Foothills Region as defined by the Reclamation Research Technical Advisory Committee (RRTAC) and in the Soil Quality Criteria Subcommittee (1981) document. The mountain ranges are strongly folded and faulted Paleozoic and Mesozoic strata with minimal metamorphism, vulcanism, and plutonism. Clayton et al. (1977) described the Rocky Mountains and their foothills as extending northwest from the 49th parallel to the Liaird Plateau and Plain. The foothills, mostly rounded hills but containing outlying mountain ridges, run parallel to the Rocky Mountains next to the Interior Plains.

The Rocky Mountains are broken by the Peace and Liaird rivers. On the east, they are bounded by broad folds of massive Paleozoic limestone and quartzite. The ridges are separated by deep valleys eroded

along folds, fractures, and relatively soft strata. The Rocky Mountains range in elevation from 1830 m to over 3660 m.

4.3.1.3 The Interior Plains. Most of Alberta is part of the Interior Plains Region (Figure 4.19) which contains virtually all the soils with significant agricultural potential. According to Clayton et al. (1977), "...the plains consists of flat lying sedimentary rocks overlying the gently sloping rim of the Precambrian Shield."

Information on geology and relief of the region and its glaciation in the next two sections is paraphrased from Clayton et al. (1977:42-47).

4.3.1.3.1 Geology and relief. The Plains are underlain by horizontal beds of sedimentary rocks ranging from Cambrian to Tertiary consisting of limestone, sandstone, and shale. Fluvial sand and gravel cover these Cretaceous deposits. Uplift followed by erosion has resulted in isolated uplands which were developed before the Pleistocene epoch. These uplands include the Cypress, Hand, and Neutral Hills of southern Alberta, and the Swan Hills, Caribou, and Horn Mountains of northern Alberta.

Drainage of the Interior Plains is towards Hudson Bay, the Gulf of Mexico, and the Arctic Ocean. The northern Interior Plains and Alberta Plateau drain northward through the Liaird, Peace, and Athabasca rivers into the MacKenzie River and then to the Arctic Ocean. The northern Interior Plains have a west-east tilt towards the MacKenzie basin.

South of the Athabasca River, most of the southern Interior Plains drain northeastward through the Saskatchewan and Red rivers into Hudson Bay. The Milk River in Alberta drains south to the Gulf of Mexico through the Missouri River system.

4.3.1.3.2 Glaciation. Following the erosion in Tertiary times, the Interior Plains were repeatedly glaciated during the Pleistocene epoch. The continental ice sheets covered the Interior Plains, coalescing with the Cordilleran glaciers of the west.

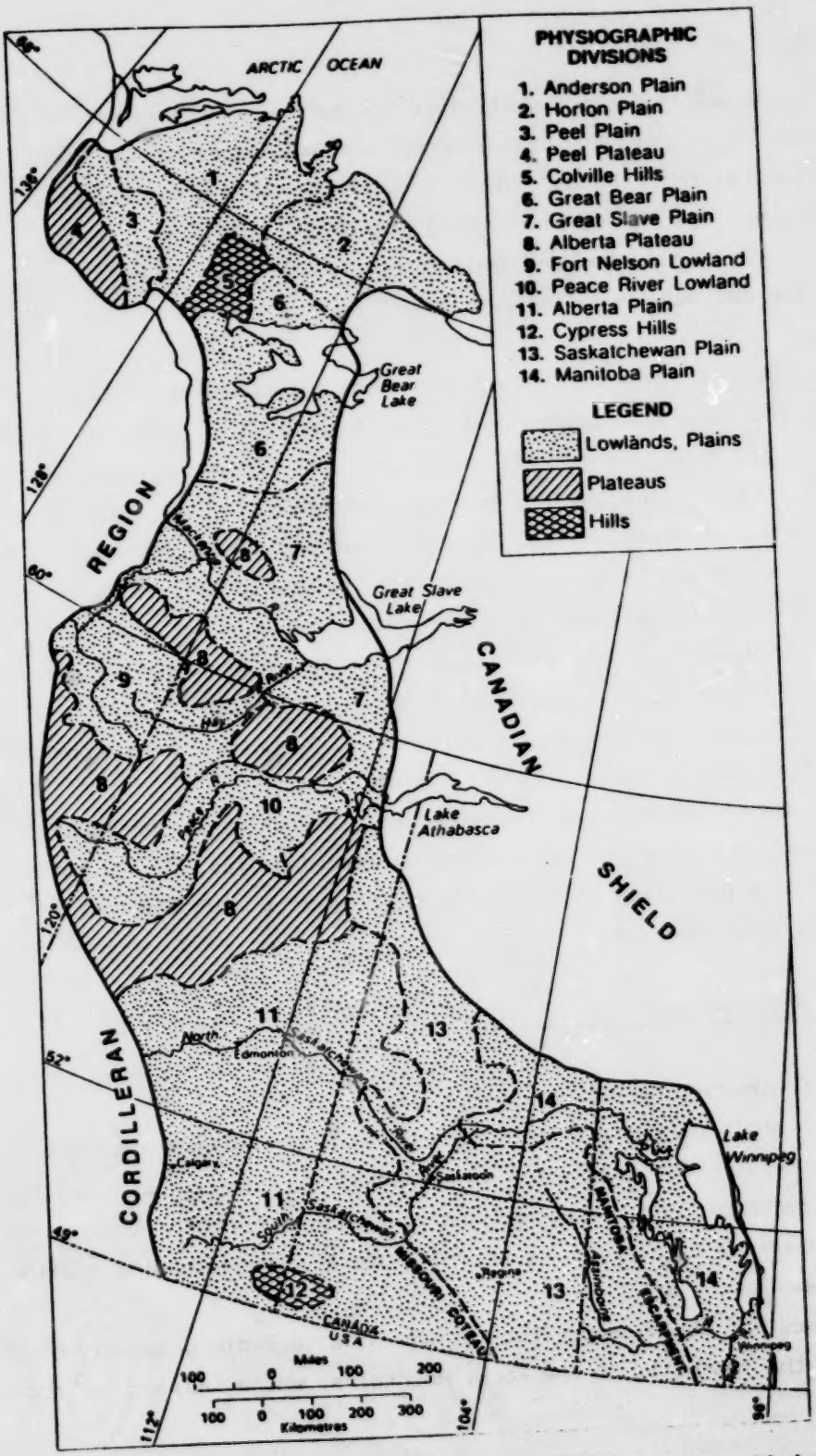


Figure 4.19. Physiographic divisions of the Interior Plains (After Bostock, Geological Survey of Canada).

Source: Clayton et al. (1977)

These glaciations determined the nature of the parent material for virtually all of the plains area, without altering the main pre-glacial relief features. This is evident from the variation in till thickness over the buried pre-glacial topography. However, mixing and deposition of transported and underlying material during melting and retreat and meltwater ponding and runoff have modified the surficial landscape.

The surficial deposits are complex with undulating till plains of ground moraine, interspersed with flat lacustrine clay and hilly end moraines. The fine clayey till in ground moraine was derived from underlying shale. Hummocky and end moraine deposits cover large areas of the southern plains west of the Manitoba Escarpment and northwest of Great Bear Lake on the northern Interior Plains. These areas are sandy or gravelly and may include stratified or resorted tills.

In late Wisconsin times, glacial lakes were formed by ponding between the higher ground to the south and the receding ice front. Small glacial lakes were located in the Drumheller, Edmonton, and Lethbridge areas of the Alberta Plain.

Associated with the fine-textured lacustrine sediments of former lake basins are coarse glacial fluvial outwash deposits. Where thick lake sediments were deposited prior to the melting of buried ice blocks a hummocky terrain developed.

4.3.1.3.3 Physiographic subdivisions.

Southern Interior Plains

A small portion of the Saskatchewan Plain extends into Alberta in the northeast. The till cover is a mixture of Precambrian granite, Paleozic limestone, and Cretaceous shales of local origin. Associated with the rough morainic deposits are many small lakes occupying shallow depressions.

West of the Missouri Coteau, the Alberta Plain gradually slopes upwards to the foothills of the Rocky Mountains, where sedimentary rocks

are upturned and the topography is rougher. In the more arid areas the soft underlying rocks have been severely dissected and form "badlands."

The Plain is covered with moralnic till deposits. The moraines form hummock knob and kettle topography in the south. Some of the flatter ground deposits in central Alberta are covered by thin deposits of lacustrine silt and clay.

Alberta Plateau

The Alberta Plateau north of the Athabasca River is a continuation of the Alberta Plain to the south. The Plateau is deeply dissected by the Hay and Peace rivers. Their wide river valleys occupy almost one half of the Plateau area. The Plateau is characterized by the widespread distribution of glacial lake deposits. Medium- to fine-textured clays are deposited in lacustrine basins of the Fort Nelson, Hay, and upper Peace River valleys. Poorly drained areas of coarser sandy deposits are found along the Athabasca and lower Peace rivers. South of the Peace River Lowland, undulating to rolling glacial till plains alternate with rough hummocky areas of knob and kettle topography.

4.4 GEOLOGY

4.4.1 An Overview

A very brief overview of the geological history of Alberta is presented drawing principally from Godfrey (1980). In a series of predominantly salt water flooding and deposition cycles (termed transgressions) sediments have been laid down over the original Precambrian bedrock. Such transgressions are typically followed by uplift or rebound, retreats of the seas and land emergence. During three of these cycles erosion subsequent to the land emergence has removed most of the sediment deposited in the preceeding transgression. Each cycle of sea transgression and land emergence is termed a period in geologic time. The various periods are shown in a much simplified form as they appear with depth in central Alberta (Edmonton) (Figures

4.20 and 4.21). By comparing the theoretical stratographic profile with the actual, the stratographic deposits which have been lost by erosion are evident.

The geologic strata dip from the northeast towards the southeast where they are overriden by the folded and faulted Rocky Mountains. Thus the depths at which the strata are found vary within the province and in general terms the strata exposed at the surface are oldest in the northeast and are younger as one moves southwest. This is illustrated in the simplified geological map (Figure 4.22). Cross sections through central and southern Alberta are also illustrated in Figure 4.23. A more accurate and detailed geological map is available from the Alberta Research Council and published in Hardy (1967).

Underlying the sedimentary strata is the Precambrian rock of the Canadian Shield which appears at the surface only in the northeast. They dip relatively uniformly to almost 6.4 km below the surface in the southwest. These granitic basement rocks are two billion plus years old and belong to the early Protezoic period. They produce very nutrient poor and weakly buffered acidic soils when exposed on the surface. In contrast many of the sedimentary strata overlying the Precambrian basement rocks are saline and sodic as they were formed in brackish marine environments and have been further salt enriched by groundwater fluxes.

In the southwest the Rocky Mountains were formed by the end of the Cretaceous period -- 65 million years ago. Lateral crustal movement buckled and folded sedimentary strata which had accumulated during the Devonian, Mississippian, and Cretaceous seas. The compression folding and shrinking of this belt continues today with much of the shortening concentrated in the weaker strata of the foothills.

Overlying much of the sedimentary strata east of the Rocky Mountains are the varied deposits of glacial calcareous till. The Pleistocene or Quaternary Ice Age began about 500 000 years ago. Continental Keewatin ice sheets advanced across the Precambrian Shield and plains from the northeast, until they abutted the mountain or

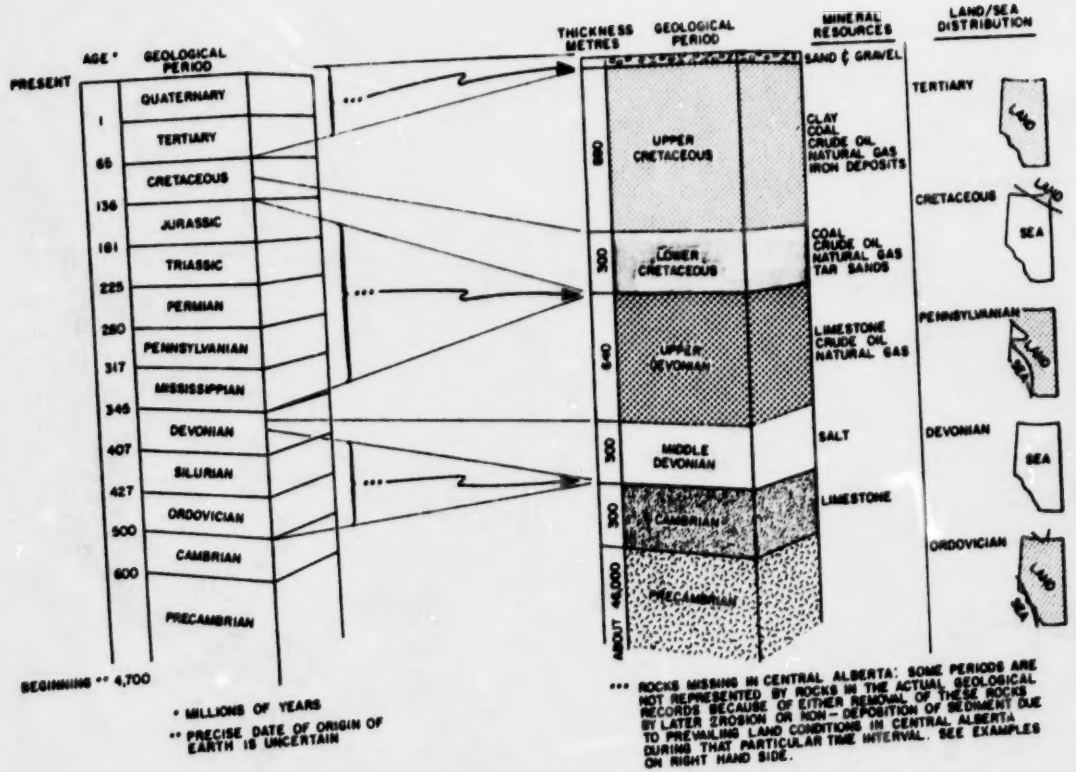


Figure 4.20. Column 'A': Theoretical Complete Geological Column

Source: Spalding (1980)

Figure 4.21. Column 'B': Geological Column in Central Alberta

Source: Spalding (1980)

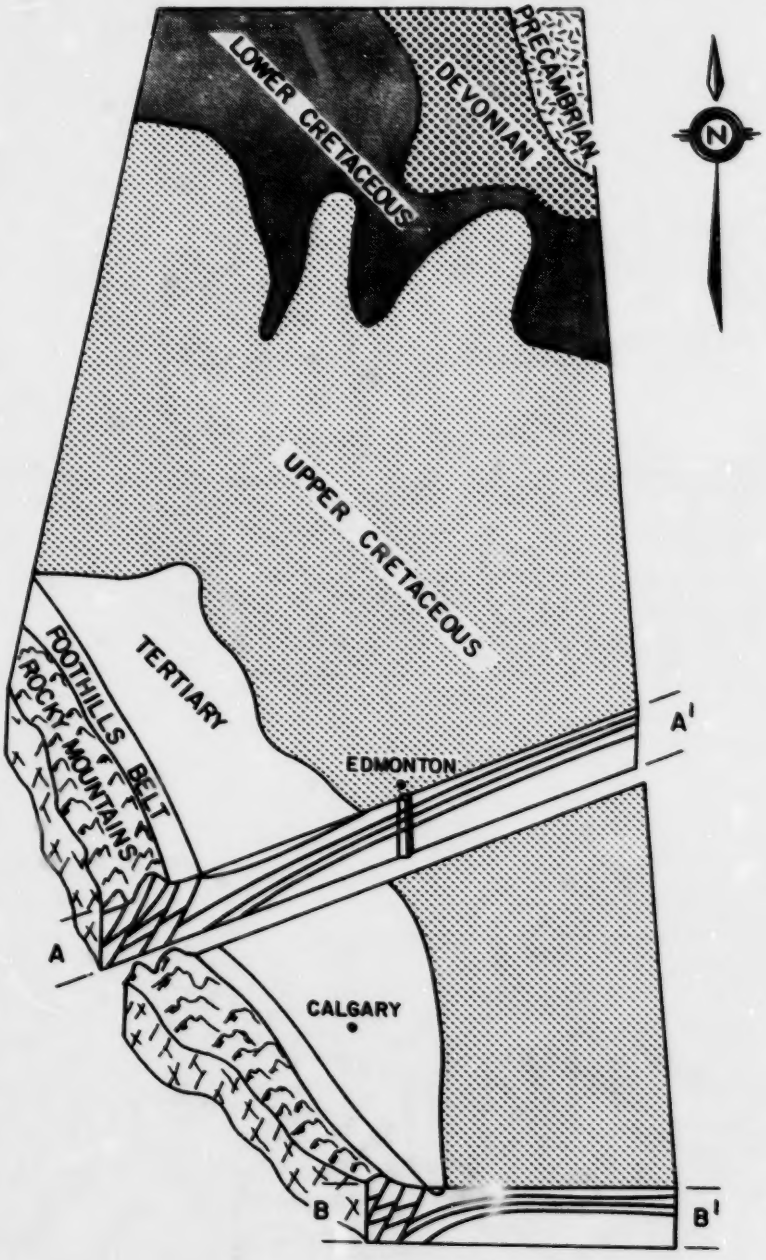


Figure 4.22. Simplified geological map of Alberta. Details of the two cross-sections are found in Figure 4.23.

Source: Spalding (1980)

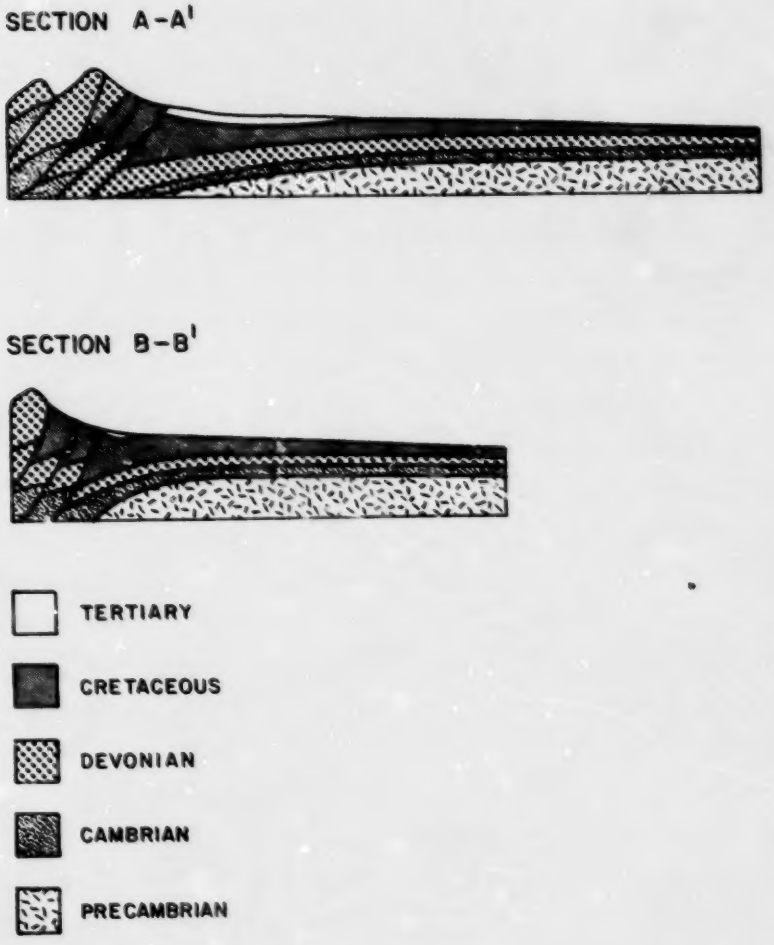


Figure 4.23. Geologic cross-sections through central (A-A') and southern (B-B') Alberta. See Figure 4.22 for location of cross-sections.

Source: Spalding (1980)

Cordilleran ice sheets in the west. The latter were formed by coalescing valley glaciers flowing eastwards from the Rocky Mountains. These two large ice sheets also coalesced and flowed southwards across the plains and into the United States. The ice sheets did not cover the mountain peaks but did erode valley walls and bottoms forming U-shaped main valleys with hanging valleys and cirques. Exposed peaks were eroded and frost shattered into aretes, cols, and matterhorns.

During the retreat of the glaciers which began about 12 000 years ago, large volumes of water and sediments were released. Drainage channels, spillways, and lakes were formed, changed often, and reformed, leaving a myriad of surface features. Major features include large spillways, some with present lake chains, drumlins, eskers, and knob and kettle topography. The most common feature, as initially indicated, is a thin mantle of calcareous till which is usually sand and gravel in texture, but may range to clay. When the ice retreat was rapid, glacial deposits were thin and mostly coarse, but whenever the ice front remained stationary for a period of time, end moraines were formed. Whenever the ice fronts blocked natural drainage channels, ice dammed lakes formed and lacustrine clays were deposited.

The current dominant geomorphological process reworking the surficial glacial and upper Cretaceous deposits is river and stream erosion. Large prairie rivers such as the North and South Saskatchewan are incising and widening their valleys. In the mountains, peak discharges during spring are eroding stream banks and beds and loading rivers such as the Bow and Liaird with silt. Alluvial fans, deltas and stream bed accretion is occuring in the glaciated river valleys, and as the rivers cross the foothills into the plains.

4.4.2 Geologic Formation of Natural Resources

Hardy (1967) described the geologic origin of the important mineral resources in Alberta.

4.4.2.1 Oil and gas. The most important geologic resource is the oil and natural gas fields which are found principally in porous rocks

associated with the Devonian, Mississippian, and Cretaceous periods. During the Middle Cambrian period the inundation of much of Alberta was limited by an embayment or headland in south-western Alberta and north-western Montana called Montania, and the Peace River Arch in the north. The latter embayment formed a broad peninsula extending north-east from what is now the Dawson Creek area in British Columbia. North of the Peace River Arch was another embayment extending into the Keg River Area of Alberta.

These embayments formed basins into which marine sediments were deposited. The strata tend to be warped upwards along the edge of these basins. Oil formed in the basin sediments and being lighter than water migrated upwards towards the edges of the basins. Overlying the Cambrian rocks, the shales and siltstones of the subsequent Ordovician period were relatively impermeable. Along the edge of the basins beach sands and limestone coral reefs were formed. The oil along the basin edges flowed up into these porous strata and thus they contain many signifcant oil and gas fields. Significant oil and gas deposits also developed in the limestone and dolomite beds of the early Carboniferous period. Oil was also trapped in middle Cretaceous beach sands in central and western Alberta south of Edmonton. During the late Cretaceous period extensive sands were deposited in the northeast portion of Alberta by the Dunvegan delta which drained through the Liaird River Valley in the Rocky Mountains and south towards the Gulf of Mexico. The deltaic sands were usually covered by thick strata of fine clays. The clays helped to trap or seal the oil in and eventually lead to the Pembina oil field formation, the largest oil formation in area in the world.

Being the youngest oil bearing formation the Pembina field is also the closest to the surface. When the erodible sandstones and siltstones which overlie the oil field are shallow enough to be exposed by exploration and exploitation serious surface erosion has occurred. The severe erosion and reclamation problems of the Swan Hills are an example. The other deeper oil formations such as those in the

Carboniferous limestone and dolomite beds cause less reclamation problems related to geologic origin.

4.4.2.2 Coal. Coal seams or strata of commercial interest were formed primarily during the Jurassic to Cretaceous and Lower Tertiary periods. At the start of Late Jurassic time, much of Alberta was inundated from the Pacific. Toward the end of the Jurassic period the Black Hills of South Dakota started to rise, creating a swamp at the head of the embayment. Continual uplift changed the swamp to shoreline, then delta, swampland again, and finally river bottom. Coal deposits are found wherever the deltas were preserved as for example the Kootenay coal in the Crowsnest Pass and in Bow Valley. During the late Jurassic period abundant vegetation growth occurred on the river deltas formed at the headwaters of the river systems as they left the embayments and flowed eastward. This resulted in coal seams along the foothills.

During the Middle Cretaceous period more extensive coal swamps developed in what is now the Rocky Mountains. The stagnant swamps allowed organic detritus to accumulate as the toxic water layers at the bottom of the swamp limited decomposition. Much of this coal developed into bituminous and semi-bituminous deposits.

During the late Cretaceous period the coals associated with the Belley River Beds were formed. These were formed from the Edmonton delta which extended over much of present day Alberta and flowed southeastward to the Gulf of Mexico. This is the source of coals of the Drumheller valley and of the outer foothills belt.

As Ziemkiewicz (1983:2-3) points, out, coal extracted from this formation accounts for much of the Alberta cropland disturbed by coal mining. "The coal is mined from the Ardley Zone running southeast from Mayerthorpe to Red Deer, and the Horseshoe Canyon Zone which runs parallel and to the east from Barrhead through Camrose to Drumheller. The Ardley Zone is surface mined near Lake Wabamun to provide coal to the Wabamun and Sundance power plants. Two additional power plants, Keephills and Genessee are presently under construction and will extend

mining southward to the town of Genessee. The Horseshoe Canyon Zone is mined on either side of the Battle River between Forestburg and Halkirk. These mines supply the Battle River Generating Station. Another power plant and mine are being developed to the south at Sheerness." (Figure 4.24).

Reclamation of soils in these agricultural zones presents serious problems. These coal seams are "overlain by bedrock" which contain a high proportion of swelling clays. When exposed to the elements the bedrock shales and sandstones break down into a material that is sticky when wet and very hard when dry (Ziemkiewicz 1983). This severely hinders plant growth and agricultural operations. In addition, as previously mentioned, since they were formed in brackish marine environments they tend to be salt rich. The groundwater hydrology has also tended to enrich these deposits with salt, especially sodium (see Chapter 4.5.3). An example are the strata of the Paskapoo formation which are the earliest Tertiary (period) or Paleocene (epoch) beds. These are formed from fine textured, fluvial deposits carried from British Columbia. The Porcupine Hills and upper part of the Cypress Hills are mainly composed of these early Tertiary rocks. In central Alberta the formation extends from Calgary to beyond Whitecourt (Hardy 1967). The Belley River, Edmonton, and Bearspaw formations are saline, fine textured and of silt and clay origin which lead to sodic spoil with poor physical structures (Webb 1982).

In reconstructing agricultural soils over such toxic spoils there is a need to isolate the reconstructed soil from the toxic spoil. This need is accentuated by the tendency towards moisture deficits in the rhizosphere during the growing season. These moisture deficits near the soil surface cause capillary uptake through the fine textured clayey spoil and the inevitable simultaneous salt movement up the profile.

To prevent this salt uptake deep buffers must be placed between the reconstructed solum and toxic sodic spoil. Ziemkiewicz (1983) shows typical generalized profiles of premining and reconstructed profiles (Figure 4.25). In this example 1.5 m of till

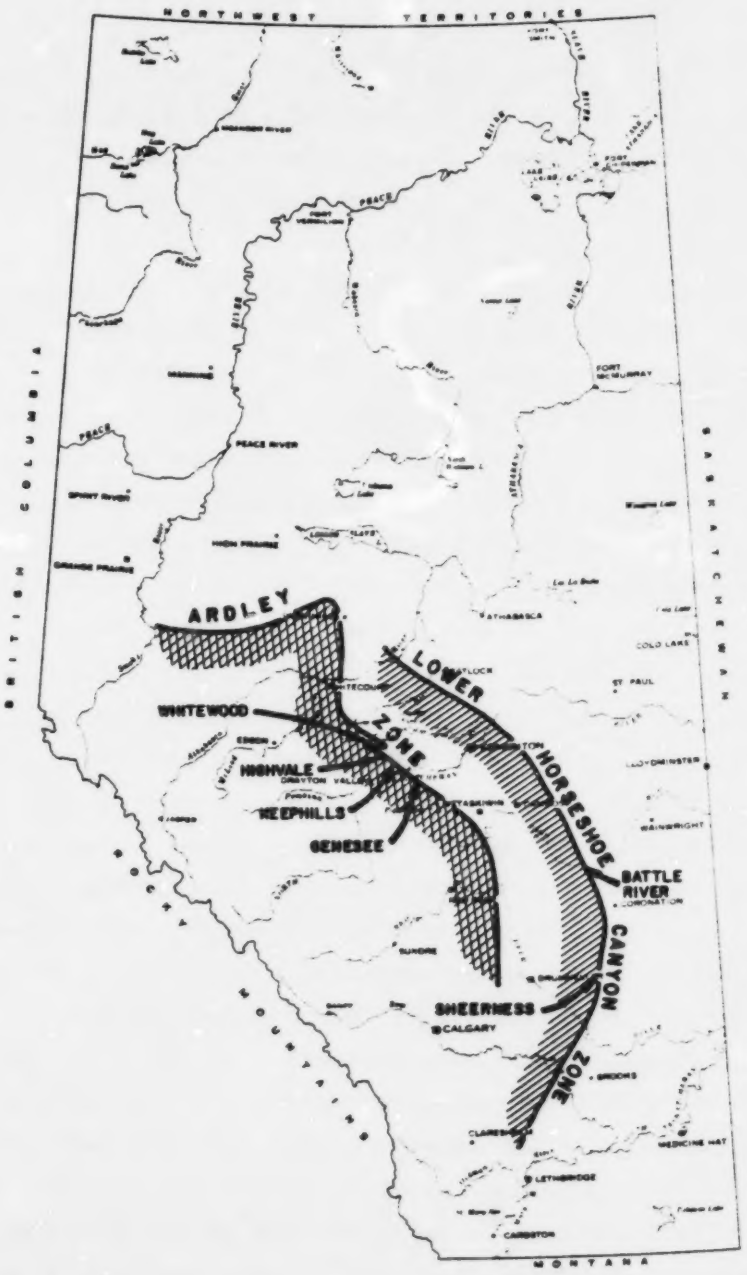


Figure 4.24. Major coal zones of the Plains Region.

Source: Ziemkiewicz (1983)

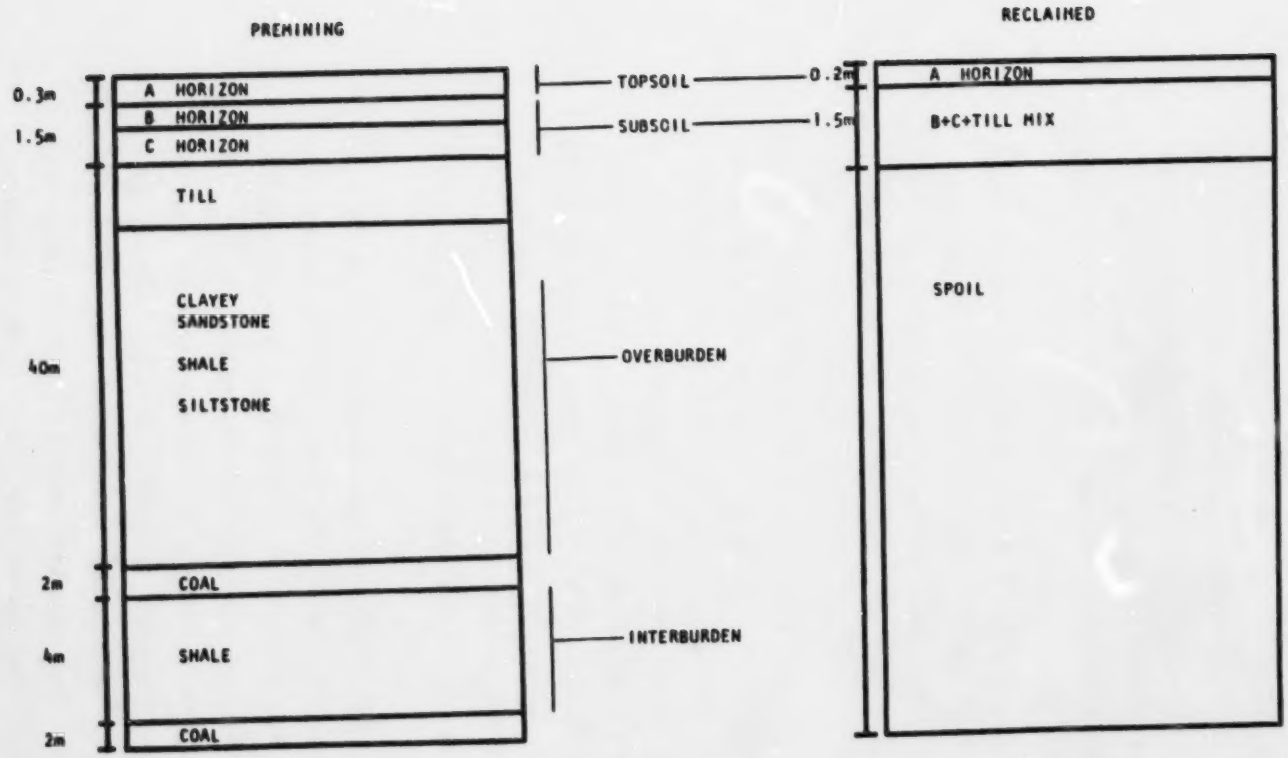


Figure 4.25. Generalized profiles of premining and reconstructed soil.

Source: Ziemkiewicz (1983)

soil mix is used as lower solum and buffer layers. In their proposed soil quality criteria the Soils Advisory Quality Subcommittee have defined the thickness of buffer needed and the nature of materials suitable for use in reconstructed soil layers and buffers. The controversial suggestion is that 3 m of solum plus buffer may be required to insure that capillary salt uptake into the rhizosphere does not occur.

Detailed soil reconstruction experiments are underway at the Battle River and Highvale sites to develop accurate soil reconstruction strategies (Figure 4.24). Included in these experiments is an assessment of bottom ash as a hydraulic barrier to net uptake into the solum.

4.4.2.3 The McMurray sands. Widely scattered, remarkably large deposits of oil sands occur in Lower Cretaceous sandstones (McMurray formation) lying above the Upper Devonian limestones and dolastones (Godfrey 1980). Hardy (1967) describes the origin of these oil sands. The oil in the tar sand deposits probably came from two sources. As streams drained towards the north, their beds incised through the Paleozoic coral reef oil pools. The oil released from the coral probably flowed with the water and was deposited with the sand along embayment shorelines.

Most of the heavy oil, however, was probably formed in situ from plants deposited in muds on top of the areas' sand deposits. As tar was formed from decomposed vegetation it was forced by overburden pressure out of the muds down into the underlying sands.

In situ mining of heavy oils or oil sands presents fairly limited surface reclamation problems; however, open pit mining of surficial oil sands deposits necessitates large scale soil reclamtion. Since the waste tailings sand is virtually devoid of nutrients as well as moisture and nutrient retention capability, it is heavily amended with peat and clay to reconstruct forest soil. Reclamation of waste overburden is complicated by toxic levels of hydrocarbons and excessive compaction or crusting. Also some overburden and surficial clay

deposits, frequently used as amendments in soil reconstruction, are excessively sodic. Fortunately extensive deposits of non-sodic calcareous lacustrine clays and bog and fenn peat also overlie the oil sands. Using these clays and peat as amendments, soil reconstruction of tailings sand and overburden is feasible.

4.5 SOILS

4.5.1 Soil Distribution

Much of the agricultural soils of Alberta have been mapped at the series level and the information made available in separate reports. Most of the natural and forested soils in the province have been surveyed at a reconnaisance level and some, such as the Athabasca Oil Sands area, have also been surveyed in detail. Generalization at the provincial level has been mostly oriented towards irrigation needs. A soil group map (Great Group level) for the province has been compiled (Figure 4.26).

More detailed descriptions of the Soil Great Groups are included in the Soils of Canada, Vol. I, Soil Report (Clayton et al. 1977). These descriptions are used in the following discussion to supplement those from the Alberta Soil Map (Brocke 1977).

Chernozemic soils or soils of the Chernozemic order in Alberta cover most of the area south of Edmonton and include the most fertile or productive and valuable agricultural soils. The Solonetzic soils in the Peace River area and in east-central Alberta are the only other moderately fertile agricultural soil resource in the province.

Chernozems are generally found in broad bands starting with Brown Chernozem soils in the southeast followed by Dark Brown Chernozems and Black Chernozems as one moves northwest. Running north and south through these bands around 112° longitude is a large area of Solonetzic soils, with Black Solonetz in the north and Brown Solonetz in the south.

The Organic soils are found in large areas of northeast and northwest Alberta with many localized outliers south of and between

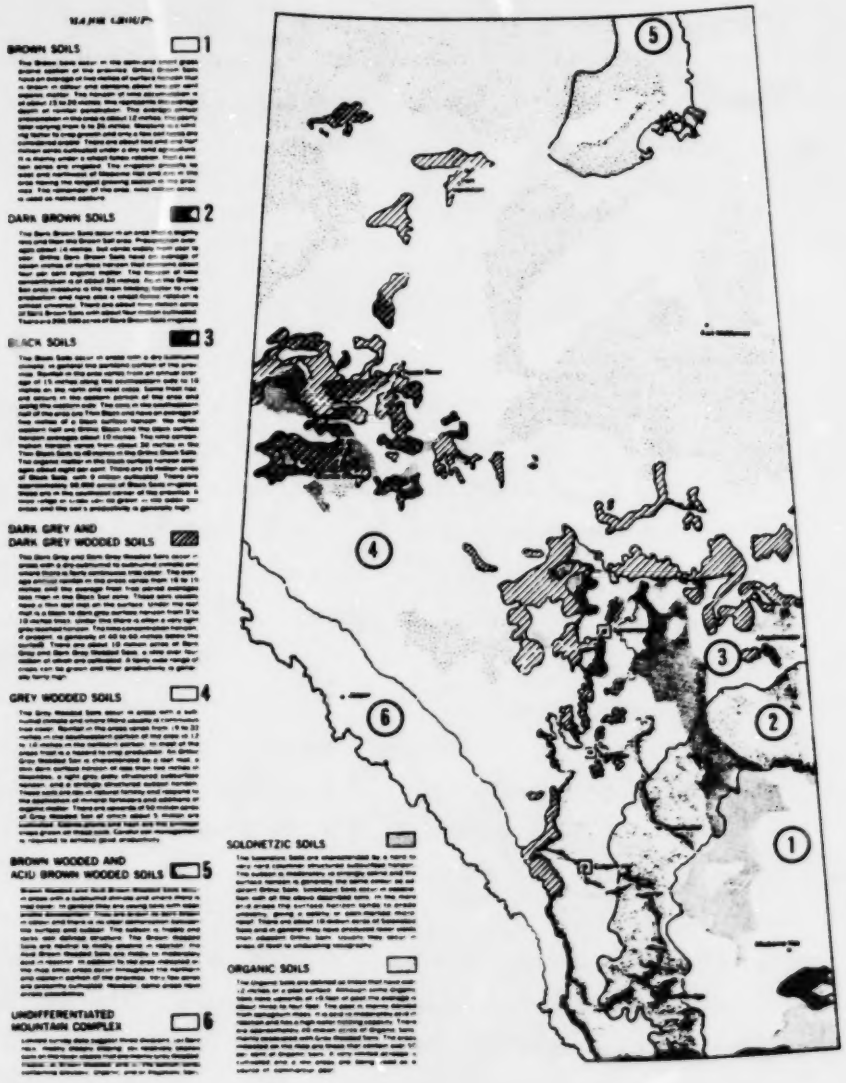


Figure 4.26. Great group soils map for Alberta.

Source: Courtesy of Alberta Research Council, Edmonton, Alberta

these two areas. At present, they are of minimal agricultural importance. All of the significant Organic soil deposits are north or west of the Chernozems. Fibrisols dominate the northwest deposit with Mesisols predominant in the northeast and outliers.

The extreme north-central portion of the province within the Great Slave Basin, lying between the organic deposits, is predominantly Gleysols with some Brunisols. Much of the remaining spatial area, south of the Gleysols and Brunisols and north of the Chernozems is Gray Luvisols (Gray Wooded Soils). The Peace River Basin is dominated by Solonetzic soils, particularly Solonetz towards the north and south ends of the basin. The mountains or Eastern Cordillera have been mapped as predominantly Rockland. The majority of soils in these areas would be various types of Regosols and weakly developed Brunisols and Luvisols. Similarly, much of the fluvial deposits of the Peace River system have been mapped as Orthic Regosols.

4.5.2 Soil Group Characteristics

4.5.2.1 Chernozemic Soils. The Chernozems have humus enriched A horizons which are thought to be developed and maintained "...by the accumulation and decomposition of a cyclic growth of xerophytic to mesophytic grasses and forbs typical of grassland or traditional grassland forest communities" (Clayton et al. 1977:100).

The Chernozems are divided into Brown, Dark Brown, Black, and Dark Grey Great Groups, the first three being predominant in Alberta.

Brown Chernozemic soils have A horizons with grayish brown to light brownish gray dry colours, which are generally lower in organic matter content than the other Chernozemic great groups. They occur in semiarid to subarid climates with severe moisture deficits. These soils have developed under a cyclic growth of xerophytic to mesophytic grasses and forbs characteristic of the Shortgrass sections of the Mixed Prairie.

Black soils are developed mainly on glacial tills, and glaciofluvial and lacustrine deposits, and less commonly on eolian,

alluvial, and colluvial materials. The inherent productivity of most Black Chernozemic soils is high, but is limited by the cool and short growing seasons and by slight moisture limitations in the growing season. Moisture limitations are enhanced by coarse soil textures. Fertility limitations on most Black soils are slight except on coarse sandy or highly calcareous materials. Nutrient levels can be maintained by standard N and P fertilization. Potassium is not usually limiting.

The problem in reclaiming Chernozem soils is primarily that they are usually Class 1 or 2 agricultural soils (i.e., highly productive and fertile). It is crucial then that reclamation to original productivity be maintained, yet equally inevitably that some loss of soil quality will result. Chernozems are not usually immediately underlain by toxic or sodic materials as may be the case in Solonetzic soils. Deeper overburden, however, may have such undesirable properties and selective handling must be designed to ensure that these undesirable materials are placed well below the solum. The Soil Quality Criteria Subcommittee (discussed in more detail later) recommended that solum plus a buffer running to 3 m be placed over toxic spoil to provide adequate protection.

4.5.2.2 Solonetzic soils. The word Solonetz is of Russian origin and was originally used to indicate saline or alkaline soils. Solonetzic soils are well to imperfectly drained mineral soils having horizon features of distinctive physical and chemical characteristics believed to result from a combination of processes of salinization by alkaline salts and desalinization by leaching within the profile.

At the subgroup level, Solonetz and Solod soils are further divided into Brown, Black, and Gray subgroups which reflect differences in the development of A horizons closely comparable to those associated with Dark Brown soils or Grey Luvisols. In addition to moisture deficits, Solonetz soils have physical and chemical limitations. The hard compact B horizon limits root penetration and periodic saline and alkaline toxicity may be a problem. The best Solonetzic soils approach

the associated Chernozemic soils in general productivity (Clayton et al. 1977).

Solonetz soils generally give moderate responses to applications of phosphorous and particularly nitrogen.

4.5.3 Pedogenesis of Salt Affected Soils

The pedogenesis of salt affected soils of the Solonetz and Solod soil orders has been described by Pawluk (1982). These soils have a particular and unique relevance to reclamation because they pose special problems, especially in the White or Agricultural area. In their natural state, these soils are the most difficult to manage and sustain agricultural productivity. Improper management can result in rapid marked pedogenesis and thus deterioration of capability. The salt enriched spoils prevalent in much of the Plains present similar management problems and strategies as do these soils. Where Solonetzic B horizon crusts have developed in the undisturbed premining soils, reclamation may enhance agricultural capability by breaking down the crusts during soil salvage. How long this benefit will persist is unknown, since no long term studies of pedogenesis of reclaimed salt affected soils have been undertaken in Alberta.

4.5.3.1 Solonetz soil formation. The Solonetz soils are found sporadically in the Interior Plains regions associated with the: (1) Brown, Dark Brown, and Black soil zones, (2) the desert, semidesert, and subhumid continental climates, and (3) relatively flat terrain. South of Edmonton they represent about 2.75 million hectares.

Solonetz soils have a compact, prismatic or columnar and alkaline B horizon and a layer of soluble carbonates and gypsum either within or below the B horizon. The indurated B horizons, particularly the Bnt horizon, is the primary feature of relevance to reclamation. The pedogenesis of these soils are mainly concerned with salt fluxes, and transformations and interactions with the clay matrix. Salinization due to rising groundwater can be followed by solonization (desalinization and alkalization) and finally solodization (dispersion

and eluviation). Figure 4.27 and Table 4.5 illustrate the soil types which can be identified along this pedogenetic cronosequence. The chernozemic pedogenetic process of calcification and humification are also included in Figure 4.27 and Table 4.5.

Since salt fluxes play such an important role in the pedogenesis of these soils, it is necessary to discuss generalized water and salt flow systems from macro-regional groundwater systems to profile scale soil water flux systems.

Regional flow groundwater systems are deep, cover long distances, and have slow flux rates. This produces long transit or residence times and brings the water into extended contact with bedrock, mineralizing more salts than other flow systems. The salt impact from regional flow systems is greatest in flat areas. Confined flow systems caused by different permeabilities of geologic strata, such as sandstone between shale, accentuate the impact of regional flow systems. Confined flow systems create artesian pressure or hydraulic heads which can enhance the upward rise and discharge of groundwater towards the soil surface.

In Alberta, the regional flow system consists of recharge in the Rocky Mountain trench, confined flow through the Devonian deposits such as the Elk Point Formation, with discharge generally along or near the edge of the Shield (Figure 4.28). The artesian pressure of the confined flow causes groundwater to be pushed up through fractures into the overlying glacial drift. Salts mineralized from the Devonian strata are discharged into the drift. These salts then did not originate from the soil parent material -- the glacial drift. Where the glacial drift tends to be thinner and the land surface fairly flat, regional salinization becomes apparent.

Where local topography is not flat intermediate flow systems influence salt fluxes. The upslope areas tend to be recharge areas and the lower slope positions discharge areas. Since the transit times are shorter and the materials along the flow path are glacial till, the solution chemistry is different from the regional system. In the

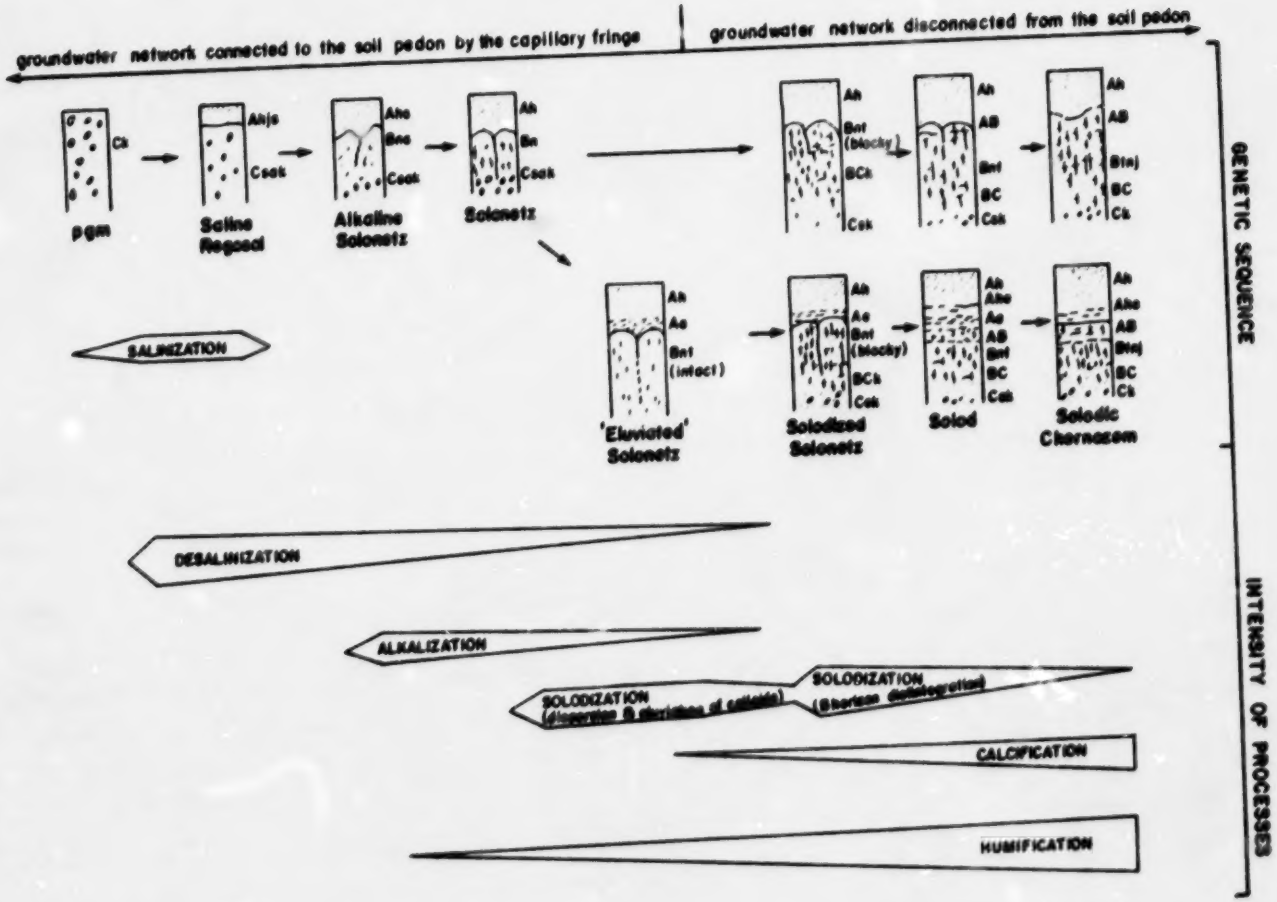


Figure 4.27. Pedogenetic cronosequence for salt affected soils in Alberta.

Source: Pawluk (1982)

Table 4.5. Terminology for pedogenetic cronosequence for salt affected soils.

Soil Order Formation	Generalized Process	Specific Process in Genetic Sequence	Process Description
Solonetz	solonization	salinization	salt accumulation
		desalinization	leaching of salts
		alkalization	adsorbed Na replaced by Ca + Al
Solod		solodization	dispersion and eluviation of clay
Chernozem		humification	organic matter accumulation
		calcification	Ca becomes the dominant cation

Source: Adapted from Pawluk (1982).

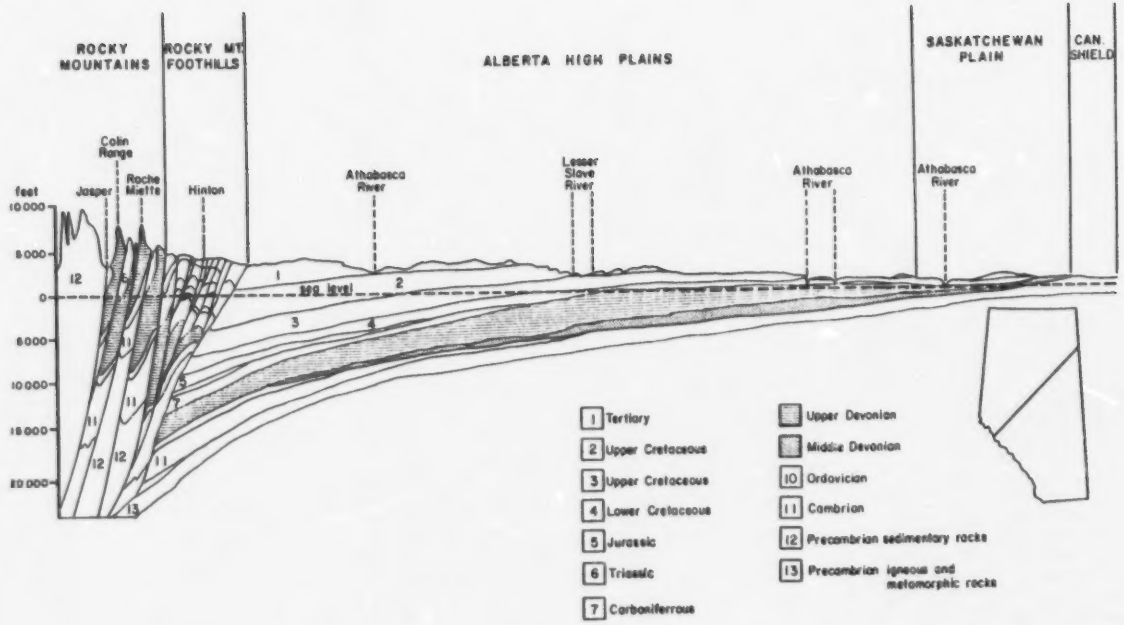


Figure 4.28. Diagrammatic cross-section illustrating interrelationships of rock units in the north central Canadian Plains.

Source: Pawluk (1982)

topographic system, calcium bicarbonate and sulphate dominate. In the regional system, sodium leached from Devonian strata dominates.

From the discussion of generalized flow systems the sources and input processes of salts to the profile are indicated. It is now necessary to focus on the flow systems within the profile. Pawluk (1982) presents such a model of profile moisture fluxes (Figure 4.29). He differentiates three active zones down the profile and above the permanent water table: (1) the unsaturated zone, (2) the capillary fringe, and (3) the phreatic zone. The unsaturated zone is well aerated and only subjected to short periodic wetting by infiltration. Soil moisture flux is almost wholly down the profile. In the capillary fringe, flux is controlled by soil moisture potential (matric), is multi-directional, slow, continuous, and restricted to the micropores. The phreatic zone of fluctuating water table has both capillary and saturated moisture fluxes. The latter is due to recharge from regional or topographic flow systems. The fluctuation in water table depth is due primarily to percolation from infiltration.

Salinization then at the profile level occurs when there is groundwater near the soil surface, high evaporative demand and limited leaching. The high groundwater table can be due to: (1) groundwater discharge from regional or topographic flow systems, (2) lateral flow, and/or (3) stagnant groundwater.

4.5.3.2 Solodization and Chernozemic soil processes. If the genetic sequence is to continue as is shown in Figure 4.27 and Table 4.5 from solonetz formation to solod and solodic Chernozem, several conditions must be met:

1. Na ions must represent a significant proportion of total salt;
2. the clay mineral must be of the expanding type;
3. the soil environment must change to one favouring desalinization either by drainage or changing climate.

If these conditions are met, desalinization begins even though salinization is still occurring. Fluxes of Na up the profile

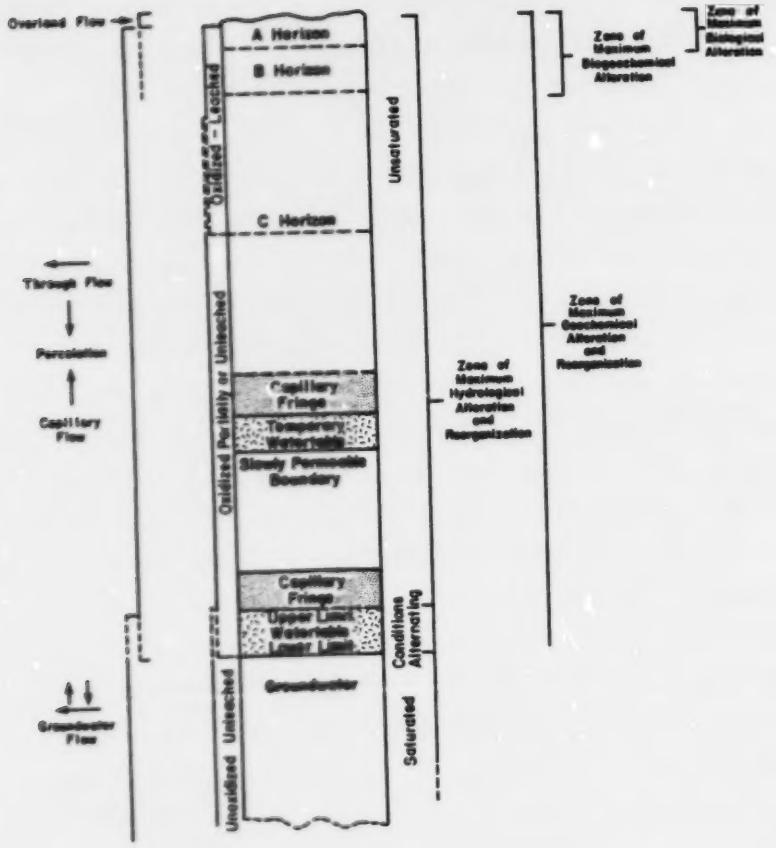


Figure 4.29. A hypothetical hydrological profile and related weathering and pedological profiles. (Note depths are variable and in some landscapes the three profiles coincide).

Source: Pawluk (1982)

occur by capillary uptake through the micropores. Simultaneously percolation and salt leaching by gravity in the meso- and macro-pores moves salt down the profile towards the groundwater. As desalinization intensifies and quantitatively becomes greater than the concurrent salinization, total salt levels in the profile, especially in the A horizons, decline. As the total salt level in the A horizon declines, dispersion of expanding clay minerals increases especially on clays with 10 to 15% or more adsorbed Na. The dispersed clay is eluviated to form incipient clay pans. Eventually this leads to a coarse textured, mildly acidic eluviated Ae horizon from which nutrients, salt, and clay have been removed and deposited primarily in an alkaline B horizon which becomes hard and less permeable (e.g., Bnt). This Bnt horizon alters the profile hydrology and initiates solodization. Moisture flow above the B horizon becomes primarily vapour flux. This limits upward Na flux. As alkalinization and weathering continue Na is replaced on the clay minerals with Al hydroxy ions and later by Ca and Mg. During prolonged wet periods, a perched water table develops above the B horizon allowing some Na recharge through capillary uptake. This causes a cycling of clay mineral hydrolosis and leaching in drier periods followed by resaturation and Na recharge during wet periods. This cycling further enhances the formation of the eluvial Ae horizons.

If the water table drops so that the capillary fringe is below the Bnt horizon for significant lengths of time, the Bnt horizon will be degraded or leached down the profile. This process will lead to solodized solonetz and solod formation. In the presence of intense humification solodic Chernozems can develop.

This pedogenetic cronosequence, specific to soils formed in glacial drift, can have some application to spoil pedogenesis. Primarily, unlike the natural or agricultural soils formed in the glacial drift, many of the spoil materials themselves are saline. Secondly, the spoils may undergo rapid pedogenesis compared to pedogenetic cronosequences in natural soils. Initial results from the Plains Coal Reclamation Research Program (PCRRP) in central Alberta suggest that if the spoils can retain their permeability under a

reconstructed soil, rapid desalinization can occur. In this situation, an intermediate topographic flow system will lead to rapid desalinization of upslope position and salinization of lower slope positions. So long as the spatial extent of salinized lower slope soils is restricted, this reclamation approach looks promising. With intense humification, one would expect the spoil pedogenetic cronosequence to tend towards chernozems. Lacking sufficient humification due probably to intense leaching, one would expect the spoil pedogenetic cronosequence to produce some type of humic luvisol. Either outcome would be acceptable to reclamation and would produce a productive stable agricultural soil.

What one gains in soil productivity, one may lose in water quality. It is possible and probable that not all of the salt generated by the intense desalinization, and pedogenesis in general, will end up in the salinized lower slope soils. If a major portion of mineralized salts reaches groundwater and spoil water tables are higher than premining levels as expected, the salt rich spoil groundwater could contaminate adjacent groundwater aquifers.

In soil reconstruction in solonetz soil areas several problems arise. It is quite common that sodic or salt rich subsoil or parent material and/or overburden may underlie the solonetz solum at fairly shallow depths. This means selective materials handling must be very precise if sodic contamination of the solum is to be avoided during soil salvage. This is perhaps most difficult during pipeline construction with only one or two phase materials handling systems. In large scale surface disturbances, such as coal mines, care must be taken in designing the reconstruction topography as well. Since saline groundwater is usually present relatively close to the soil surface the final water table should be no closer or ideally deeper in the profile to prevent salinization by capillary uptake.

Conversely, disturbance could theoretically have beneficial effects on agricultural productivity. Soil disturbance can break up solonetzic pans, increasing vertical conductivity and ultimately salt leaching down the profile. If the natural pedogenetic forces are

towards salinization or solonization the pans are likely to reform. Thus the beneficial effect of disturbance could be ephemeral, although there are little data and thus no consensus on how long it would take, for example, for a Bnt horizon to re-evolve. If the soil was a pedorelic (i.e., formed in an environment which has since changed) the pans may not reform and the beneficial effects may be more long term. Furthermore such a disturbed soil could evolve into a solod or a chernozem.

4.5.3.3 Luvisolic soils. At the great group level, Luvisol soils are separated into Gray Brown Luvisols and Gray Luvisols. Gray Luvisols predominate in Alberta. The Gray Brown Luvisols have developed under deciduous or mixed-forest vegetation, mostly under Mesic humid climates. Because of high biological activity, including that of earthworms, they are characterized by a rapid incorporation of forest litter (L-F-H material) to form dark coloured "forest mull" types of A horizons. In contrast, the Gray Luvisols have largely developed under Boreal forest vegetation and Boreal to Cryoboreal climates and are characterized by accumulations of slowly decomposing leaf litters, L-F-H layers, and thin or absent Ah or Ahe horizons.

Dark Gray Luvisols are characterized by thicker and frequently darker Ah horizons than those of the Orthic subgroup. Dark Gray Luvisol soils with increasing depth of Ah horizons approach and intergrade in characteristics and properties with Dark Gray Chernozemic soils. These two soils are frequently associated, particularly within zones of forest-grassland transition.

Luvisols are most frequently associated with other forest soils (Organic, Brunisolic, and Podzolic) but in areas of forest-grassland transition are more frequently found with Dark Gray Chernozemic and Gleysolic soils.

Much of the Gray Luvisols in the cold and cool climate regions of Alberta are under mixed-wood or coniferous forest. The agricultural productivity of the Luvisols varies markedly with climate, profile development, and parent material. Agricultural productivity on

Gray Luvisols in Alberta is limited by climate, and soil structure and fertility problems. Climatic problems are associated with the short growing seasons, high probabilities of frost damage, early winter freezing, and delayed spring thawing. Soil structure and fertility problems are related to limited organic matter in the plough layer (Ap horizon), a lack of friable soil structure or tilth, low natural fertility and high acidity. Heavy N, P, and often S fertilization is required. Occasionally, liming is beneficial (Clayton et al. 1977).

4.5.3.4 Brunisols. Brunisols include a broad range of imperfectly to well drained mineral soils developed under various types of forest, alpine, or tundra vegetation. They occur under Mesic to Arctic temperature regimes and perhumid to semiarid moisture regimes. They have a brownish Bm horizon markedly different in colour, structure, and composition from the rest of the profile. There is however, insufficient illuviation to form an illuvial B horizon. Because leaching and weathering are limited in Brunisols, they tend to reflect the chemical characteristics, particularly base status and pH, of their parent materials.

Brunisols are divided into the great groups: (1) Melanic Brunisol, (2) Eutric Brunisol, (3) Sombric Brunisol, and (4) Dystric Brunisol; Eutric Brunisols predominating in Alberta. Brunisols, particularly Eutric Brunisols, are important in soil reclamation in the foothills and Athabasca Oil Sands area. The Melanic and Eutric Brunisols are both developed on high base status, usually calcareous parent materials. The Melanic Brunisols have a distinctive dark surface Ah horizon. Eutric Brunisols lack the dark Ah horizon. They have developed under forest or alpine vegetation and under Boreal, Subarctic or Arctic climates and usually occur on basic or calcareous parent materials.

Brunisols tend to be found with Podzolic and Luvisolic soils and with Rockland areas. Most Brunisols in Alberta are Alpine Brunisols developed on coarse to medium textured glacial till, outwash, and eolian deposits. The Eutric Brunisols in Alberta are mostly within

the Great Slave Plain and the Northern Plateau and the moutainous area of the north-west.

Very little agricultural development has taken place within Eutric Brunisol areas.

4.5.3.5 Organic soils. Organic soils have developed largely from organic deposits. By definition, they contain in excess of 30% organic matter by weight and meet minimum specifications of depth and thickness within a defined control section. Organic soils are commonly associated with Gleysolic, Brunisolic, Luvisolic, and Podzolic soils, and to a lesser degree with Regosolic soil and Rockland. Organic soils and layers may be found overlying a wide range of mineral materials ranging from glacial tills and outwash to alluvial lacustrine sediments. In areas where underlying mineral layers are moderately calcareous till, alluvial or lacustrine deposits, terric Organic soils are usually acid to neutral and of high base status and tend to favour the development of Fenn rather than Sphagnum types. Organic soils developed on non-calcareous tills or bedrock, particularly in the Canadian Shield, tend to be more highly acidic and usually of the Sphagnum or Woody types.

The topography of most Organic soil areas in Canada is level to very gently sloping on the macroscale, but may be hummocky to roughly undulating in micro relationship. With drainage, proper tillage and fertilization these soils can be very productive for agriculture. Strongly acidic organic soils with low base saturation, such as acidic sphagnum dome bogs require significant liming for agricultural utilization. Organic soils are typically prone to macro- and micronutrient deficiencies.

Virtually all significant peat deposits in Alberta are Mesisols or Fibrisols. Peat utilization is important in reclamation of waste overburden and tailings sand in the Oil Sands area. As the benefits of peat utilization become more well-known its use is becoming more widespread (e.g., in reclaiming gravel pits).

The other soil orders, Cryosols and Podzols are rare and limited in area and will not be discussed. Podzols, for example, are primarily limited to the small portion of Shield in the northeast of the province. Regosols and Gleysols while present over large areas, are very complex, precluding meaningful generalizations and discussion on a province wide basis. Furthermore, Gleysols have minimal agricultural, and rather limited forestry significance while Regosols though predominant in the mountainous areas and important in the foothills, have only been studied on a very limited basis.

4.5.3.6 Soil catenas in the foothills and mountains. In the coal mining areas in the foothills and mountains much of the most productive forest soils are Luvisols and Brunisols. Organic soils in the same areas could be utilized to significant benefit as supplementary amendments. Conversely the many types of regosols, colluvial, and alluvial deposits and cryosols at high altitudes are least important. With the latter types of soils the most important reclamation objective is probably erosion control. Some of these soils might also support high alpine meadow and streambank meadows. The Luvisols and Brunisols in the foothills have significant potential for commercial forestry and recreation uses. The gleyed and organic suborders of Luvisols and Brunisols and the many peaty Organic soils also support significant areas of high and low meadow which in turn are important for ungulate grazing.

The distribution of these various types of soils often can be represented by catenas, especially in relation to relief. A very crude generalized catena suggesting where these soils tend to occur is illustrated in Figure 4.30. It is drawn in a very general way from the work of Pettapiece (1971) who presents a scholarly account of an actual mountain soil system. The theme of the discussion here is that relief is the prime determinant of soil pedogenesis and thus soil productivity. While this is probably valid, the work of Holland and Corns (1980) suggested that climate, which is primarily controlled

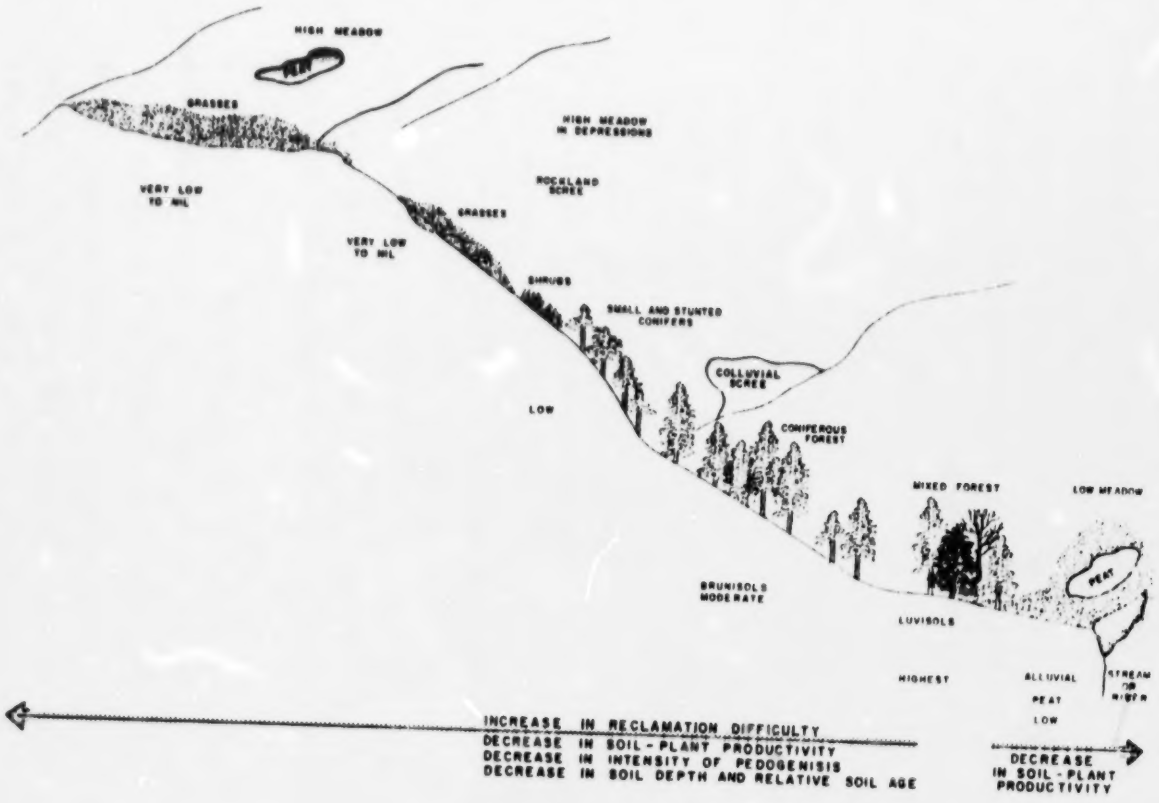


Figure 4.30. Alpine catena displaying pedogenetic crono-sequence controlled by relief.

Source: Figure by J. A. Campbell (1983)

locally by relief, was the dominant factor limiting forest and vegetative growth in these mountainous and hilly ecosystems.

The catena in Figure 4.30 suggests the most productive soil zone is in the mid and lower slopes where the Brunisols and Luvisols occur. Above and below this zone are the meadows on gleyed and organic type soils consisting of little or slightly altered source material. This catena sequence of productivity also reflects in a general way a pedogenetic cronosequence from little altered parent material to deep well developed profiles perhaps even the beginings of podzolization in the clayey Luvisols. At the lower elevations, in flat peaty and gleyed clays, pedogenesis is retarded or limited by anaerbiosis due to excessive moisture. At higher elevations, cold temperatures are also important in retarding pedogenesis.

The Luvisols and Brunisols being the most productive must be reclaimed to commercial and recreation forest uses. These soils on gentle to fairly steep slopes present a variety of reclamation problems. The Luvisols, typically on gentle slopes and with deep A horizons and sola, are easiest to reclaim. The Brunisols tend to be, or can be, on steeper slopes. This combined with very thin A horizons presents significant operational soil salvage problems. Windrowing the trees prior to soil salvage, which is commonly done, results in most of the fertile A horizon and significant parts of the B horizon being lost. Natural windthrow is part of the normal pedogenesis of these soils and is probably beneficial to the nutrient and elemental cycling in the soil; however, it occurs slowly over the slope as a whole. By contrast, windrowing exposes large areas of the slope to erosion and must result in significant losses of N and P from the soil elemental cycling system before salvage and after respreading. One alternative to windrowing is to use surface rotovation with machinery that can mulch small trees and large tree trunks. This allows surface soil horizons to be salvaged with less dilution from subsoil. The added wood mulch also helps to reduce erosion on steeper slopes when respread.

To replace capital losses of N, P, and organic matter in reconstructed sandy soils (from Brunisols), peat from nearby low lying deposits could, in certain cases, be utilized. Typically such peats would have from 1 to 2% N and 40 to 60% organic carbon. Although P is often low in these deposits, fertilizer P added is rapidly fixed in most peats and then very slowly released to plant uptake. Lacking peat, P fertilization, especially in soils reconstructed from Brunisols, would be ineffective since much of the P would be leached through the profile. Peat amendment would also increase the moisture holding capacity and lower the erosion potential on slopes.

At present the high alpine meadows seem to be most threatened by the coal mining activity since this mining occurs along seams in exposed outcrops at higher elevations in the foothills and mountains. These soils are also the most difficult to reclaim since low temperatures, exposure, lack of available moisture, wind, and harsh conditions in general, limit both the rate of soil development and plant growth and establishment. In addition the soil resource is very limited (i.e., thin and often sporadic). Materials handling is more expensive especially if materials have to be moved long distances up and down slopes. Special care should be made to salvage high altitude peat and peaty gleys as organic amendments for reconstructing high alpine meadows.

Although the various other gleysols, regosols, cryosols and non-soil materials may have low productivity, improper handling of these areas can threaten nearby higher productivity soils and/or the aquatic resources. Excessive erosion due to slope instability can cause eutrophication and sediment pollution of streams, lakes, and rivers as well as negative impacts on adjacent Luvisiols and Brunisols or reconstructed soils of higher productivity.

4.5.4 Soil Quality

Generally, disturbed lands are reclaimed to one three types of land use: (1) agriculture, (2) forestry, and (3) recreation and wildlife habitat, or for other reasons such as aesthetic and erosion

control purposes. Occasionally, reclaimed sites are used for construction, urban expansion, and other purposes. Alberta law requires reclamation to an equal or superior site capability or to a condition such as that existing before disturbance. Therefore, there is a need to assess soil quality before disturbance and after reclamation. The review of specific literature in this document indicates that the latter process is difficult. Attempts to develop criteria are inevitably controversial (Soil Quality Criteria Subcommittee 1981). The assessment of soil quality before disturbance is more straightforward and has been done nationally as part of the Canada Land Inventory. The Inventory includes capability for agriculture, recreation, and forestry; however, that for agriculture is more detailed. Similar to the soil survey, land capability classification, particularly for agriculture, has been done extensively at the farm or soil series level. Generalizations have been made at the provincial and national level.

As a resource, agricultural soils and potential agricultural soils in Alberta are very significant. They represent not only a large portion of Alberta but of the national total; only Saskatchewan has a higher percentage of agricultural soils (Selner 1974). Saskatchewan also has higher quality soils for agriculture (Environment Canada Lands Directorate 1976).

4.5.5 Soil Degradation by Disturbance

Degradation is the loss or deterioration, in whole or in part, of the quality of the soil resource due to resource extraction and subsequent reclamation or abandonment. Thus it includes deterioration or lessened quality of reclaimed or reconstructed soils as compared to the premining agricultural or natural soils, and the total loss of soil to permanent structures, transportation corridors, and non-reclaimed surface and spoils.

Comprehensive statistics on disturbed versus reclaimed areas have not been compiled, let alone statistics on premining versus post mining soil quality. Nevertheless, some statistics and estimates have

been reported in the 18th Annual Alberta Soil Science Workshop (1981) on soil degradation (Harapiak 1981). The symposium proceedings also provide a good context with which to evaluate the impact of physical mining disturbance and reclamation on soil quality in relation to other causes of soil degradation or threats to the soil resource.

It has been estimated that by the year 2004, more than 28 000 ha will be disturbed by coal mining at any one time in the Plains region of Alberta. Thus almost 69 000 ha will be disturbed between 1975 and 2004 (Thompson 1981). Mining infrastructure such as haul roads and rail lines would double this figure. This annual rate of land disturbance by coal mining is 10 times that lost to urbanization in Alberta. Urbanized land however, can be considered lost, whereas mined land can be reclaimed or reconstructed. Almost 70% of the spatial extent of the coal fields are overlain by Class 1 to 4 land and 21% under Class 1 and 2 (Canada Land Inventory). Despite the requirement to reconstruct mine land to capability equal or better than the premining condition some continuing soil degradation is inevitable. It will be very difficult to reconstruct soils to stable Class 1 and 2 levels if such were the premining level.

Bentley (1981) compared the various causes or sources of agricultural soil degradation. He estimated surface mining would account for no more than 0.3% of possible yield losses (Table 4.6). In the eastern slopes and forested regions of Alberta, resource extraction would represent a much more significant proportion of soil degradation.

4.6 CLASSIFICATION AND MAPPING OF THE BIOPHYSICAL ENVIRONMENT

Biophysical or ecological mapping is an attempt to integrate various aspects of the environment such as geomorphology, soils, fauna, flora, hydrology, and climate into typical units having similar characteristics. Using the concept of physiography, Canada has been mapped, at a very generalized scale, into physiographic regions. Most of Alberta is classified as Interior Plains with the Cordilleran Region occupying the southwestern portion of the province, and a small portion of the Canadian Shield in the northeast corner (Clayton et al. 1977).

Table 4.6. Estimates of soil degradation causes in Alberta, 1981.

	Soil Deterioration:	Possible Yield Loss %
1.	Fertility: Loss of organic matter and nitrogen	20
2.	Physical impairment: Tilth, structure, aggregation, bulk density, compaction, infiltration, etc.	6
3.	Salinity: 10% of area, say 50% yield thereon	5
4.	Acidity: 25% of area suffering 20% decline	5
5.	Erosion: Wind and water	4
6.	Non-agricultural uses (removals per year including mining or resource extraction and urbanization)	0.3
		40

Source: Adapted from Bentley (1981).

Each region has been further subdivided into physiographic divisions (e.g., the Interior Plains as shown in Figure 4.19). Glaciation has been the single most important factor determining the nature of surficial deposits and their morphology.

The concept of ecological land classification has recently been developed and promoted through the Lands Directorate of Environment Canada. Table 4.7 presents a structural outline of the system (Environmental Conservation Service Task Force, n.d.). It consists of five generalized levels extending through a hierarchy from Ecoregions mapped at scales between 1:3 000 000 and 1:1 000 000, to the smallest units, Ecoelements, mapped at 1:10 000 to 1:25 000. Thus through the federal Environment department has come a new emphasis or bias on ecology, especially natural vegetation systems, undisturbed, and ecologically sensitive ecosystems. Much of the application of such ecologically based mapping has been towards environmental impact assessment, Arctic and subarctic environments, and wetlands. These are areas and applications which were not emphasized by agriculture-oriented soil survey.

Table 4.7. Levels of ecological generalization proposed by the Canada Committee on Ecological (Biophysical) Land Classification.

Level of generalization Common map scale[a]	Examples of common benchmarks for recognition					
	Geomorphology	Soils	Vegetation	Climate	Water	Fauna
Ecoregion 1:3 000 000 to 1:1 000 000	Large order landforms or assemblages of regional landforms	Great groups or associations thereof	Plant regions or assemblages of plant regions	Meso or small order macro	Large water basins	Assemblages of faunal communities
Ecodistrict 1:500 000 to 1:125 000	Regional landform or assemblages thereof	Subgroups or associations thereof	Plant districts or assemblages of plant districts	Meso or large order micro	Drainage pattern; water quality	Faunal community or some specialized specialized habitat
Ecosection 1:250,000 to 1:50 000	Assemblages of local landforms or a local landform	Family or associations thereof	Plant associations or assemblages thereof	Large order micro to small order micro	River reaches lakes and shoreland	Specialized habitat within a community or a lower order community
Ecosite[b] 1:50 000 to 1:10 000	A local landform or portion thereof	Soil series or an association of series	Plant association or community	Small order micro	Subdivision of above	Portions of a community or total habitats of some small species
Ecoelement 1:10 000 to 1:2 500	Portion of or a local landform	Phases of soil series or a soil series	Parts of a plant assoc. or sub-association	Small order micro	Sections of small streams	

Definitions for the levels of generalization.

Ecoprovince: An area of the earth's surface characterized major assemblages of structural or surface forms, faunal realms, vegetation, hydrological, soil, and climatic zones.

Ecoregion: A part of an ecoprovince characterized by distinctive ecological responses to climate as expressed by the development of vegetation, soils, water, fauna, etc.

Ecodistrict: A part of an ecoregion characterized by distinctive assemblages of relief, geology, geomorphology, vegetation, soils, water, and fauna.

Ecosection: A part of an ecodistrict throughout which there is a recurring assemblage of terrain, soils, vegetation.

Ecosite: A part of a ecosection in which there is a relative uniformity of parent material, soil, hydrology, and vegetation.

Ecoelement: A part of an ecosite displaying uniform soil, topographical, vegetative, and hydrological characteristics.

Source: Canada Department of Environment (year unknown)

[a] Map scales should not be taken too restrictively, as they will vary with the setting and objectives of the survey.

[b] More so than others, this level is frequently subdivided into phases to indicate a passing or temporary state (e.g., seral)

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SECTION II

MINING AND LAND RESTORATION OPERATIONS

5. OVERBURDEN EXCAVATION AND HANDLING METHODS

The problem of strip mining is not one of avoiding land disturbance but of how to disturb it with the least environmental damage. Environmentally, strip mining effects are known and can be controlled. However, mining methods must be tested for their practicality and feasibility, cost analyses of these methods must be developed, mine simulation programs have to be developed with built in reclamation plans, and suggested methods must be tested in the field. Selective mining is increasing and requires development of new equipment as well as concurrent reclamation practices (Stephanko, Ramani and Ferko 1973).

The final product of any given mining-reclamation function will fall into one of the following categories: (1) no segregation of materials; (2) some segregation of materials; and (3) extensive segregation of materials. In the no segregation category, all mining and reclamation practices that tend to mix the entire soil-bedrock profile will be found. The second category defines those systems in which one horizon has been selectively excavated and replaced but all other material is mixed. It is further assumed that the selectively handled horizon becomes the uppermost in the profile of disturbed materials. An example of this is the replacement of topsoil on a mixed bedrock spoil. The final classification is one in which more than one horizon is selectively placed. Disturbed land with selective placement of topsoil and subsoil is in this category (Techman Ltd. 1977).

One strong force that is changing the state of the art of surface mining and also creating equipment needs is the enactment of surface mining and reclamation laws. Mine operators are using specialized equipment for grading and preparing the surface of spoil banks for revegetation to abide by reclamation regulations established by the principal coal producing provinces and states (Habeck and Staff 1975).

5.1 MINING OPERATIONS

Surface mining is defined as: any process of removing the soil, rock, and other strata in order to uncover the underlying mineral or fuel deposit (Grim and Hill 1974).

Strip mining is defined as: a type of surface mining in which the overburden is removed in narrow bands, one cut at a time (Grim and Hill 1974). Types of strip mining are area mining and contour mining.

5.1.1 Area Mining

Area mining is characteristic for gently rolling to relatively flat terrain. It generally utilizes the overcasting method of spoil replacement whereby the overburden from succeeding cuts is deposited in the cut just excavated. Large equipment such as draglines, shovels, and bucket-wheel excavators are generally used (Grim and Hill 1974).

Area mining in Alberta is carried out in regions of flat-lying coal (mainly the plains) and in the oil sands region.

5.1.2 Contour Mining

Contour mining is characteristically used for hilly to very steep terrain. In Alberta it is used in mountain and foothills regions, where it is usually referred to as open pit and truck and shovel mining.

The method has a number of variations that may be used depending upon local conditions of physiography, topography, overburden characteristics, climate, and potential environmental problems.

The conventional contour mining method consists of removing the overburden from the coal seam(s), starting at the outcrop and advancing around the hillside. Using this method, spoil is subject to severe weathering, erosion, and landslides that may result in pollution from toxic materials in the spoil and highwall. The area of land disturbance is much larger than the area covered by the coal seam(s) (Grim and Hill 1974).

By the slope reduction method vegetation is removed from the top of the final highwall to the toe of the fill. Overburden is removed from the first cut and pushed downslope. Spoil is spread and compacted

in 1 m layers until the storage angle is reached. Coal is removed but a 5 m barrier is left at the toe of the cut. Overburden from the second cut is removed and stored immediately above that of the first cut. Coal is removed and the spoil is pushed against the highwall and sloped to the specified grade. A modification of this method is called the parallel fill method. Spoil from the first cut is compacted in 1 m layers until maximum depth is reached for the degree of original ground slope. Spoil from the second cut is deposited in the area of the first cut and a roadway is constructed between the first and second-cut spoils (Grim and Hill 1974).

In the box-cut method the surface layer of overburden is removed from the top of the final highwall to the toe of the fill. Overburden is removed to the final highwall to an elevation about 5 m above the coal seam, creating a flat bench from the highwall to the crest of the spoil on the downslope (allowing for 38° angle of repose). A road is constructed at the crest of the fill bench. Overburden is then removed from half of the solid bench at the highwall side (creating the first pit) and spoil is stacked between the first pit and the road. Coal is removed from the first pit and first pit spoil is pushed against the highwall. Overburden is then removed from the second half of the solid bench (creating the second pit) and spoil is stacked between the second pit and the road. Coal is removed in the second pit, leaving at least a 5 m barrier, and spoil is pushed into the second pit and the bench area sloped to a specified grade (Grim and Hill 1974).

The head-of-hollow fill method requires removal of vegetation, storage of topsoil, and construction of French drains in water courses. Crowned fill is constructed in compacted layers not exceeding 3.3 m, with crowned terraces vertically every 6 m of approximately 6 m in width; the outer slope should not be steeper than 2:1. Silt control structures are constructed downstream from the fill. Revegetation is carried out concurrently as the fill height increases (Grim and Hill 1974).

The block-cut method of contour strip mining involves the removal of topsoil by scrapers or dozers to a location just below the

outcrop. The overburden is then removed from the box-cut up to the final highwall and the coal removed.

Overburden and coal is excavated in adjacent blocks in an alternating sequence in order to assure and maintain a constant flow of coal. Stacked overburden material is contoured and topsoil placed on the surface (Saperstein and Secor 1973).

Using the mountain-top removal method the entire overburden layer above the coal seam is removed. This requires selection and preparation of sites for excess spoils storage. The first cut is mined as a box-cut and the overburden transported to the storage area. Subsequent cuts are mined parallel to the box-cut and the overburden is deposited in the previously excavated cuts (50%) and storage areas (50%). The mountain top is graded nearly flat and covered with a 15 cm layer of topsoil (Grim and Hill 1974).

The reader is advised to consult Techman Ltd. (1977), Cook, Gantner and McNay (1975), Habeck and Staff (1975), Grim and Hill (1974), and Stephanko, Ramani and Ferko (1973) for more detailed descriptions of the above methods. These publications contain sequential schematics of mining operations, models of mining plans, economics of the various methods plus advantages and disadvantages of some. A more detailed presentation of this information is beyond the scope of this Review. Other references of more limited value include Cook and Kelly (1976), Goris and Howland (1976), Anonymous (1975), Grim (1975), Allen (1973), Heine and Guckert (1973), Howland (1973), Saperstein and Secor (1973), and U.S. Environmental Protection Agency (1973).

5.2 EXCAVATION SYSTEMS

The report by Chopiuk and Chekerda (1982:2-1 to 2-19) presents an examination of the handling methods for excavations. Their discussion is repeated here in entirety by permission of those authors.

5.2.1 Equipment Alternatives

The choices of equipment for selectively handling topsoil, subsoil, and overburden materials are dictated to a large degree by the

kind of equipment an operator presently has on the site. Those operators suddenly faced with the requirement of salvaging several metres of material where, earlier, no such operation was necessary, are perhaps in a more difficult position than a new operator just planning his operation. The mine planning in the latter case can take into account this special handling requirement. The goal in either of these situations is the excavation, transport and placement of the materials at the lowest possible cost. For the operator already using the most efficient stripping method, the additional requirement of selectivley handling either 1, 2 or 3 m of topsoil/subsoil will simply add to the overall cost of mining. Since disposal or replacement of existing on-site equipment is probably not feasible, particularly in the case of major stripping machinery such as draglines, the question then becomes one of which choice of machines will perform this special task adequately at the lowest additional cost.

The operator who is contemplating the development of a new property is in a different situation. He has the option of choosing his major stripping machines with the knowledge that he must allow for the selective handling requirements of his permit or license. His choice of equipment for the selective handling requirement may be completely different from that of an operator who is presently running an economical operation. The age of existing equipment, for example, could dictate whether new machines will be brought on-site all at once, or whether they will be phased in as the older machines are retired.

In addition to the usual factors that are considered in the selection of the stripping method such as the nature of the overburden, the life and production rate of the operation, the geological structure, size and distribution of the coal deposit, topography, etc. legislation requiring certain reclamation practices must also be considered. Factors such as end use of the land will dictate slopes and, therefore, the amount of grading which must be done; whether the reclaimed land will be used for crop production, rangeland, or commercial/industrial sites will determine the amount, if any, of topsoil/subsoil that must be salvaged.

Table 5.1 outlines some of the choices that may be considered when evaluating various types of equipment for the removal of topsoil and subsoil. Haul distance and flexibility obviously eliminate some machines from consideration.

Since no two mines are identical, the kinds of equipment chosen at one mine may not be suitable for another. The advantages of reducing the variety of machines used at a mine to minimize repair and maintenance costs would be one example which would influence selection, for example.

Following are discussions of the various methods that might be used in a selective materials handling scheme. The suitability of each type of equipment is examined briefly for this objective from a technical/operational point of view. The economic evaluations regarding capital expenditure and operating costs are reviewed in detail separatley for each kind of equipment [in Section 5 through 9 of Chopiuk and Chekerda 1982].

5.2.1.1 Draglines. Within the Ardley coal zone, the dragline is the most common primary stripping unit. Its chief advantage is its efficiency in removing and placing overburden at one of the lowest costs per unit volume of material. The main drawback of the dragline when considering selective placement, is its inability to place the upper-most soils in the original overburden profile at the top of the cast material without seriously affecting its productivity. In addition, a certain amount of soils and overburden mixing takes place, making the removal of thin layers of subsoil and topsoil difficult. An illustration of the simplest operation of a dragline is shown in Figure 5.1. No selective removal or placement is being done, and none of the overburden material is handled more than once. The dragline size (bucket volume and boom reach) is chosen to serve a specific mine pit requirement. The boom length, for example, will limit the depth of overburden that can be excavated using the procedure shown in Figure 5.1 (no material re-handle). Beyond this depth the dragline can still operate, but either of two methods must be employed: (1) the dragline will have to use some overburden to build itself a bench in the open pit from which to operate,

Table 5.1. Topsoil removal versus equipment rating.

1. Should be considered 2. May be considered 3. May be considered under certain conditions 4. May be considered special situation A. High B. Moderate C. Low		Dozers	Front-end loaders	Scrapers			Dragline	Shovel and truck	Bucket wheel excavator	Front-end loader and truck combination
				Elevating	Full-power	With push tractor				
Topsoil thickness	0 to 0.6 m	1	1	1	1	1	3			1
	0.6 to 1.5 m	1	1	1	1	1	3	4	3	1
Haul distance	0 to 91 m	1	1	2	2	1	3			
	91 to 152 m	2	2	1	1	1	4		3	
	152 to 305 m			1	1	1		4		3
	305 to 457 m			1	1	1		4		2
	305 to 457 m			2	2	2		4		1
Flexibility under varied field conditions	Good	A	A	A	A	A	A	A	B	A
	Fair	A	A	A	A	A	A	B	B	B
	Poor	B	B	B	B	B	A	C	C	C

Source: Adapted from USBM, economic engineering analysis of U.S. surface coal mines and effective land reclamation, contract S0241049, February, 1975. (Original not seen; information taken from Chopiuk and Chekerda, 1982)

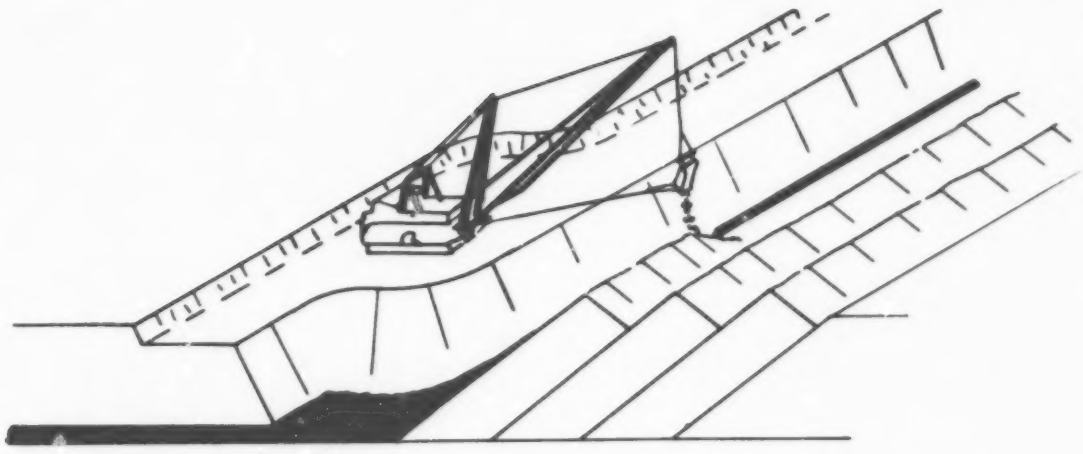

Figure 5.1. Dragline stripping

Source: Chopiuk and Chekerda (1982)

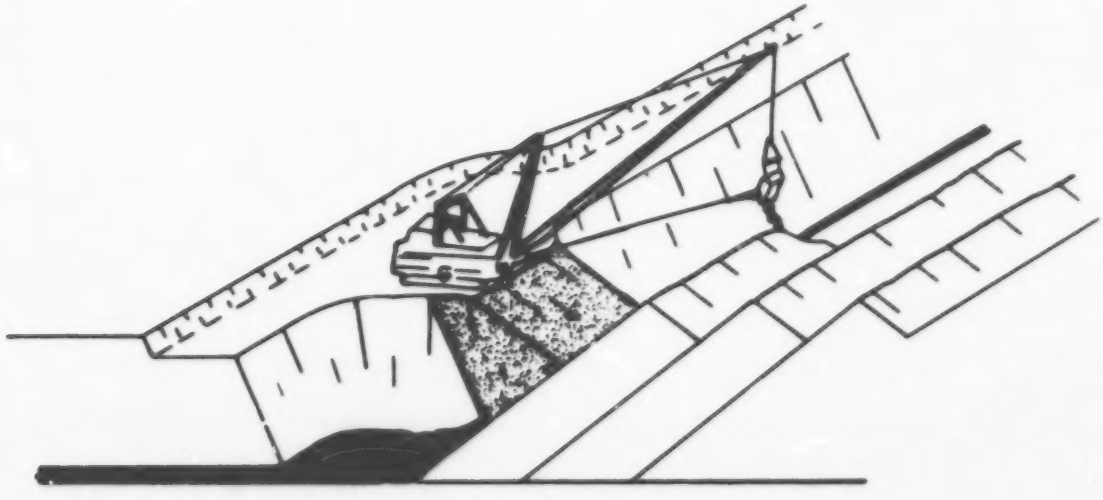

Figure 5.2. Dragline stripping with rehandle

Source: Chopiuk and Chekerda (1982)

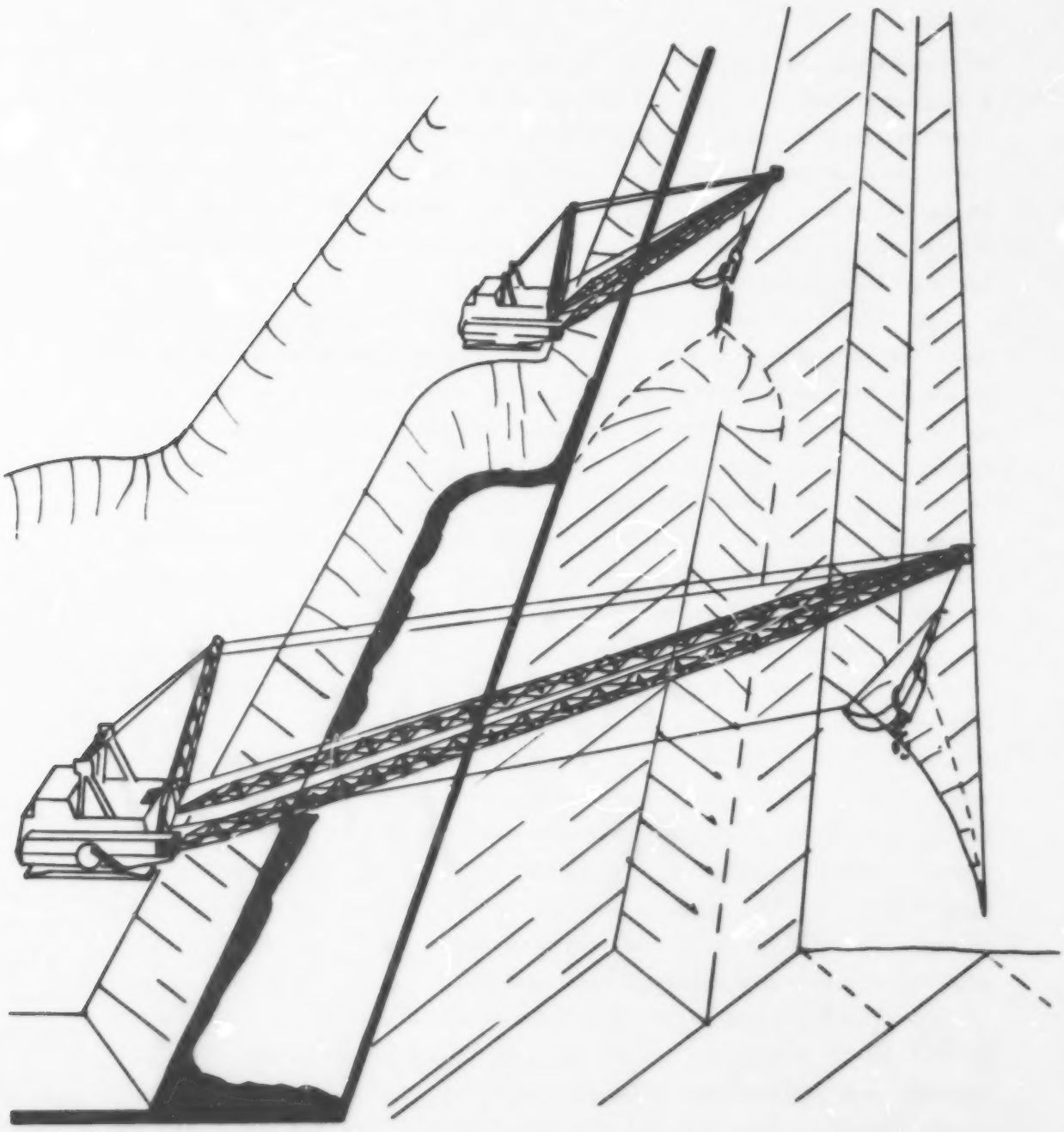

Figure 5.3. Two dragline operation

Source: Chopiuk and Chekerda (1982)

thus allowing the cast material to be placed further back in the spoil area (see Figure 5.2), or (2) enough material must be removed by some other method that reduces the depth that the dragline must excavate to the optimum depth, so that no re-handle is involved. This operation may be called pre-stripping or benching down. In the first choice, the greater the depth of material to be excavated beyond optimum, the greater the amount of re-handle.

The problem of reclamation still remains, however. In normal operation, the dragline is not able to place the upper-most original soil on top of the spoil piles. Instead, this material is usually lost at the bottom of the spoil, since it is the first material to be excavated. Placing this preferred material at the top would either require extended benching and large swing angles or a longer boom to allow placement of the selected material on top of the other spoil. Both of these methods reduce the efficiency of the dragline, and this extra cost can be attributed to the cost of reclamation.

Rather than using the primary dragline for reclamation or selective handling purposes, a second dragline with a longer boom has been proposed. This could be a smaller capacity machine with a boom of 500 to 600 ft (153 to 183 m). This second dragline would sit on the same bench as the primary unit and would excavate the upper layers of subsoil/overburden, casting these materials behind the spoil pile or row placed by the main dragline. An illustration of this is shown in Figure 5.3. For an existing operation, this second unit would not normally be required until the operation encountered deeper overburden, assuming no selective handling was required.

Some grading of the spoil ridges would be required prior to the subsoil being placed on top of the previously-placed lower spoil. Problems are encountered, however, with this two-dragline approach. First, long-boom draglines are not being built at the present time, and so the choice is purely academic. The second difficulty arises in avoiding the machines boom interfering with each other, as might occur if the second unit is placed on the spoil side of the pit. To this time

there are no companies who are using the dragline for selective handling purposes.

Draglines are being used in some operations as pull-back draglines. Sitting on the spoil, these machines are used to level the spoil rows cast by the primary excavating machine.

5.2.1.2 Scrapers. Scrapers are commonly used in many surface mining operations for road construction, grading, coal cleaning and parting removal, etc. They are also used for the removal and stockpiling of topsoil ahead of the advancing pit, and in recontouring spoil piles to establish a finished grade.

Their capability to selectively remove and place different materials is relatively good. If the need is present, scrapers are able to build separate stockpiles of subsoil and topsoil and then replace these materials in their original layers. The kind of material being excavated and the condition of the site will play a large part in determining how well this placement can be done. Although in theory there should be no problem in spreading even lifts of 0.12 m (e.g., topsoil cover over subsoil), actual experience in the field shows that this is not always the case. Even attempting a 0.5 m evenly-spread lift can be sometimes almost impossible, particularly when the material is wet. The rutting created by the loaded scrapers makes even placement very difficult and clayey materials will come out of the scraper in large lumps rather than in a smooth flow. Weather, therefore, can seriously affect a scraper operation and how effective it can be in selective handling.

Scrapers have a high degree of mobility, and can be directed to other areas of the operation when spare time becomes available. Support equipment, such as push dozers to assist in loading, and a grader and water truck to maintain haul roads if a large scraper fleet is used, is usually required. Congestion on the site may become a problem, depending on the number of units employed. Costs increase as haul distances increase from the highwall around the end of the pit to the levelled

spoil. Bridges or ramps might be one answer to reducing cycle times and lowering scraper operation costs.

Another problem which can arise when using scrapers to place subsoil and topsoil is overcompaction of clayey materials. This can result in hard impervious layers. Reduced infiltration of water, leading to excessive runoff and erosion can also make the establishment of vegetation difficult. Ripping can be one solution. Another might be to place the material in thick lifts of 1 m or less rather than the thin lifts used in construction where a high degree of compaction is required. As noted before, placing material when it is wet is difficult and also results in excess compaction. Reducing the number of times the machines are driven over the soil will also help.

5.2.1.3 Trucks and loaders/shovels. A truck/loader or a truck/shovel system can also be used to remove and selectively place the topsoil and subsoil layers as well as deeper overburden if required. The ability to segregate materials being removed depends somewhat on the depth of each layer when considering the loader or shovel. Placement of the materials can be controlled reasonably well by directing the trucks to dump in the required locations.

5.2.1.3.1 Trucks. Various types of off-highway trucks are available as well as a selection of sizes. Choices of type include bottom-dump, rear-dump, side-dump, conventional unit (body mounted on the truck chassis), tractor-trailer unit; two-axle, three-axle configuration, etc. Transmission types include manual, automatic, mechanical, electric drive, etc. Sizes range from 27 to 272 t.

Popular maximum size used for mining operations is around 154 t. Mechanical drives normally are available up to about 109 t, from where electric drives are almost exclusively supplied.

In general the choice will depend on the ability to make the most use of the equipment for the variety of applications required. Loading the trucks with shovels or loaders requires that units be matched in terms of loading time and ability to reach the top of the truck. The

selection of trucks used for overburden will be determined to a great extent by conditions that exist at a mine such as where units are being used for hauling coal, for example.

5.2.1.3.2 Loaders. Front-end loaders are becoming more popular in surface mining operations. They are versatile in the kinds of jobs they can do and are also highly mobile. Loaders can load coal, strip overburden, build and maintain roads, and strip and stockpile topsoil and subsoil. On short distances (e.g., 1 km or less) they can function as hauling machines, particularly the larger units. Loaders are able to strip layers of material reasonably well without mixing and so lend themselves to use in selective materials handling. A stripping machine can also double as a coal-loading unit.

The selection of the size of loader will take into account the production required and whether or not the loaders must match a haul truck which may already be on site in terms of reach, dump height, bucket width, etc. Manufacturers supply loaders having bucket sizes ranging from 2 m^3 to as much as 24 m^3 or more. Mechanical or electric drives are available.

Traction can be a problem in wet conditions, as the crowd or loading action is achieved by forward movement of the loader. The ability to position the bucket over the truck is dependant on steering and machine motion; both factors can lead to high loading times, thereby increasing overall cycle times. Operator skill becomes very important, and it is unlikely that loader production could match shovel production for machines of equal size.

5.2.1.3.3 Shovels. A shovel/truck operation is similar in many respects to the truck/loader system. A shovel's digging action is somewhat different from a loader's. Shovels tend to mix different materials to a greater extent since the vertical action of the bucket cuts across the materials as the bucket fills. Digging below ground level is not practical. As with loaders, bucket size, boom reach, etc. must be matched to the haulers that are used.

Shovels are used at many mines for coal loading, with the largest units employed for stripping and spoiling overburden. The shovel's ability to rotate on its frame lead to faster loading times compared with loaders. High break-out force and long life expectance are other advantages of the shovel, although break-out force is not as important in soft overburden removal as it would be for loading coal. Its limited versatility and restricted mobility because of being track-mounted are drawbacks compared to loaders.

Both electric rope shovels and hydraulic shovels are available. The hydraulic shovel is perhaps better suited to overburden stripping, as it has greater ability to pick and sort thin layers of materials, similar to the loader. Its life expectance may not be as high. However, only one operator is required (no oiler).

5.2.1.4 Bucket wheel excavator. Use of the bucket wheel excavator (BWE) for removing overburden at coal strip mines in Canada has not begun to date. Bucket wheel excavator's are removing both tar sands deposits and overburden at two operations in Fort McMurray, Alberta, beginning in 1967. Several bucket wheels are presently operating in the United States, and serious consideration is being given to introducing at least one to Alberta coal mines. European mines have been using BWE's for a number of years, particularly in Germany.

The large capital investment required for a BWE makes its application for removing only thin layers of topsoil or subsoil questionable. When this surface work is a part of a major stripping operation, the machine can be utilized to its full potential.

A BWE does have a number of advantages compared to other excavating machines. It is usually smaller than a comparable dragline or shovel of equal production capability. The BWE digs continuously and, therefore, has no cycle times; this also contributes to lower instantaneous power requirements since no surge loading occurs. Its ability to mine materials selectivley is reasonably good, although very thin layers such as topsoil would have to be bulldozed into windrows to allow the wheel to work more efficiently. A wheel could remove a 100 mm

lift, but at greatly reduced output. Normally the minimum lift that can be removed efficiently be a bucket wheel is about 0.5 to 0.7 of the wheel diameter. With typical diameters of 5 to 9 m this means removing lifts of at least 2.5 m.

The BWE's main drawbacks are its lack of versatility or mobility. Extremely hard materials may be difficult to handle without ripping or blasting. Boulders can be handled with some extra caution and the right operating procedures.

5.2.1.4.1 Operation. A bucket wheel uses either of two cutting method when digging: a terrace cut or a drop cut. A terrace cut (shown in Figure 5.4) maintains a constant wheel height, while a drop cut (shown in Figure 5.5) maintains a constant slice thickness. In addition, there are different digging methods which can be used. To be able to selectivley remove thin layers of different materials such as topsoil or subsoil, the face block method is used. An illustration is given in Figure 5.6. Travel distances are greater for this method, and long bucket wheel booms are required. Each different layer is removed from the working block separately; then the wheel is dropped down to the next layer and it is removed.

Where selection of layers is not important, the usual digging pattern used is the full block method. This is shown in Figure 5.7. This is the predominant method for BWE's today.

In most strip mine applications, the material will have to be removed from the BWE, since the reach of the discharge conveyor on the machine is not long enough. The wheel may be used to load trucks, similar to a loader or a shovel operation. This study will, however, examine the cases where the bucket wheel discharge is directed onto two different types of conveyor system -- the cross-pit bridge conveyor and the shiftable round-the-pit conveyor system. These are discussed briefly in the following two subsections [and examined in more detail in Section 9 of Chopiuk and Checkerda 1982].

Depending on the mine plan, the BWE may be the primary or even the only stripping machine. It may also be brought on site to assist an

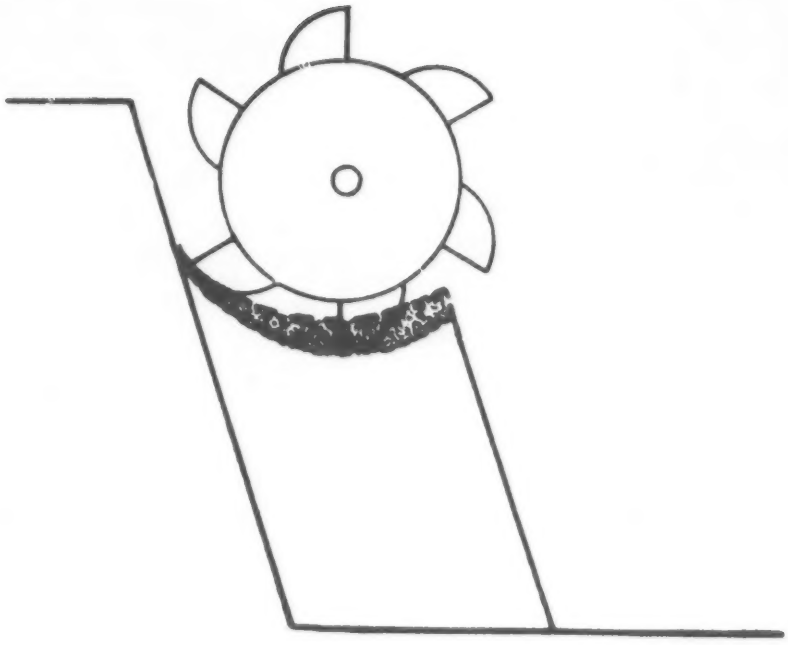

Figure 5.4. Terrace cut

Source: Chopiuk and Chekerda (1982)

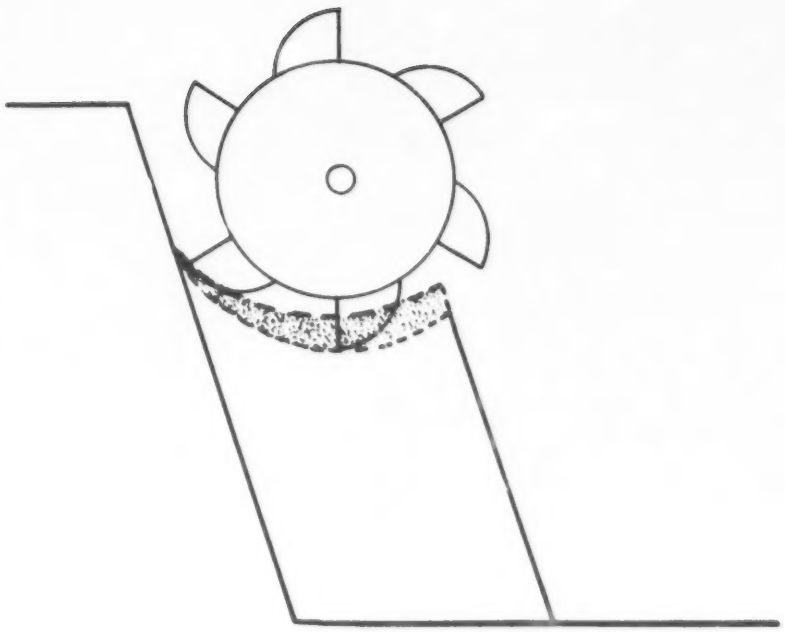

Figure 5.5. Dropping cut

Source: Chopiuk and Chekerda (1982)

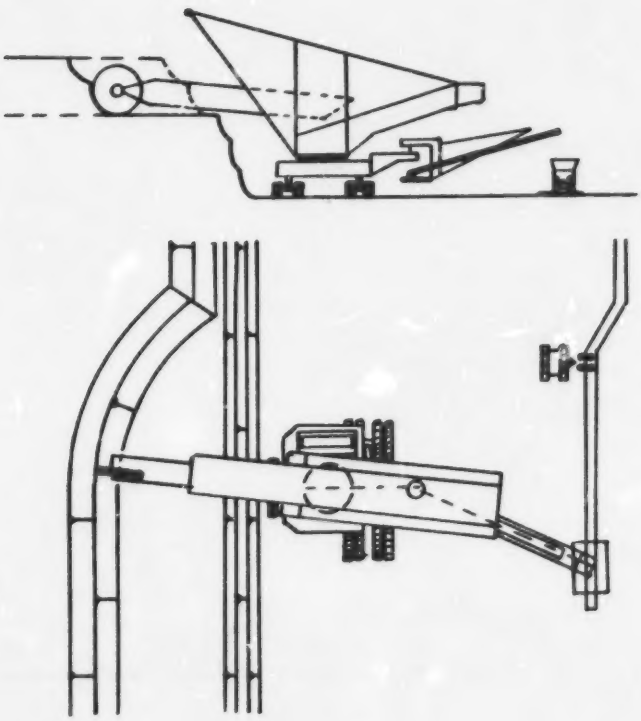

Figure 5.6. Face-block excavation

Source: Chopiuk and Chekerda (1982)

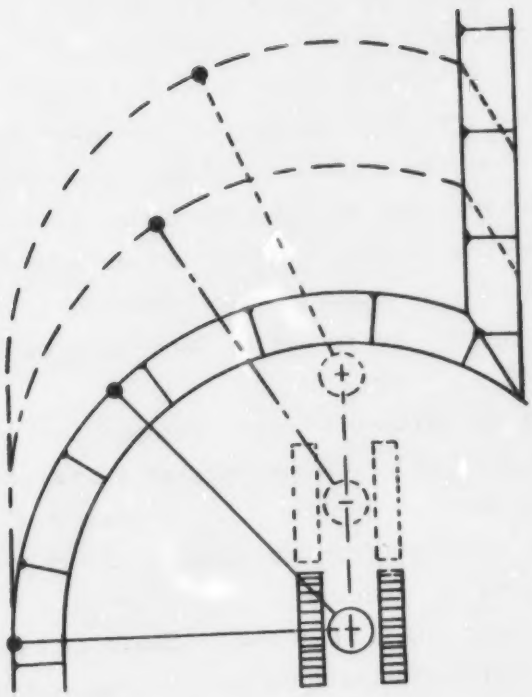

Figure 5.7. Full-block excavation

Source: Chopiuk and Chekerda (1982)

existing dragline when that unit has reached or exceeded its optimum digging depth.

5.2.1.5 Cross-pit conveyors. The use of cross-pit conveyors in surface mines in North America is a relatively recent development. Very few are operating at present, but the concept is being considered for Alberta mines. The cross-pit conveyor is basically an ordinary belt conveyor supported by a structural steel bridge, spanning the open pit between the highwall and the spoil as depicted in Figure 5.8. The bridge is supported on either end by a powered crawler undercarriage which allows the bridge to be moved up and down along the pit. The conveyor is fed at the highwall using a loading machine such as a loader, shovel or dragline, but most commonly by a bucket wheel excavator. The materials discharged at the spoil end are spread by some sort of stacker or shiftable conveyor.

Another type of cross-pit conveyor uses the idea of a cantilevered bridge, supported at one end only by a powered undercarriage on the highwall side as shown in Figure 5.9. Each accomplishes the same result -- transporting material from one side to the other, with the added capability of selective handling.

In February 1980, the Coal Mining Research Centre published a detailed study of the application of cross-pit bridge systems in prairie surface coal mines in Alberta. A specific objective was to examine the suitability of such systems in selective mining and reclamation of the topsoil and upper layer of glacial till. In the study, the two-support bridge was recommended over the single-support belt-wagon crosspit system which did not have adequate selective placement capabilities and required a higher capital investment.

A number of operational considerations were also addressed such as working schemes for selective mining and dumping, bridge operation at the ends of the pit and location of haulage ramps.

5.2.1.6 Round-pit shiftable conveyors. Shiftable conveyors are presently being used in some surface coal mines in the United States. A

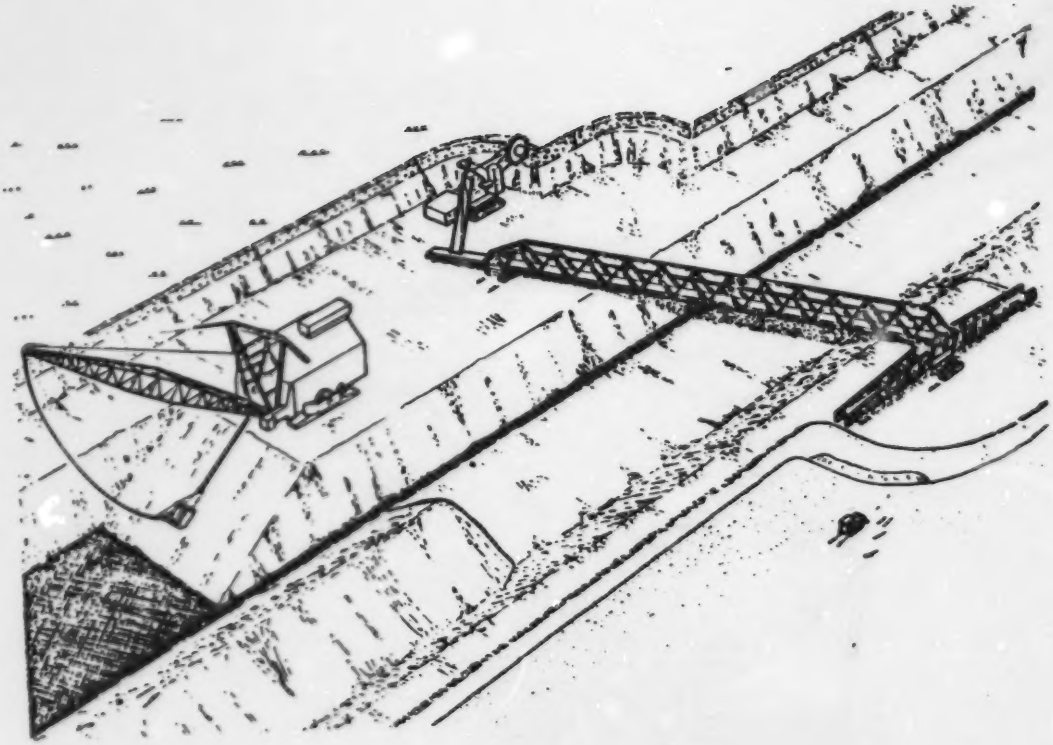

Figure 5.8 BWE, cross-pit conveyor, stacker (moving soil, till and overburden), dragline (moving overburden).

Source: Chopiuk and Chekerda (1982).

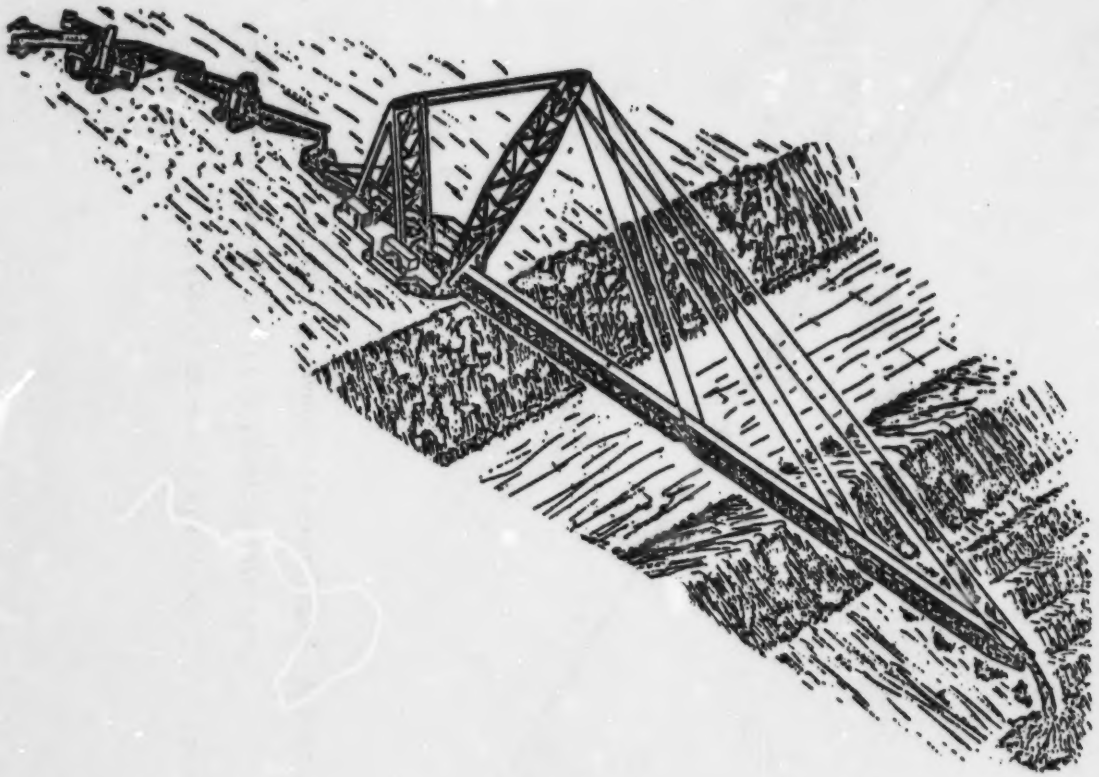

Figure 5.9 Single-support cross-pit conveyor system.

Source: Chopiuk and Chekerda (1982).

section of such a conveyor is shown in Figure 5.10. Sections are assembled to provide a continuous length of conveyor along the highwall of the pit, a side conveyor length, and a conveyor on the spoil side running the length of the pit. A complete system might be composed of one large system or two smaller systems, one around each end of the pit beginning and ending at the middle of the pit as shown in Figure 5.11.

A suitable conveyor system will allow the bucket wheel excavator, for example, to work farther ahead of the dragline, since spanning the pit with a bridge is not involved. Spreading the soil can be done several spoil rows back from the pit for the same reason, aiding in spoil stability. The large number of pieces do increase the probability of breakdown, and pit access ramps become restricted.

A movable hopper and cable car are located on the highwall when the system received material from the excavator (bucket wheel). The spoil conveyor has a travelling tripper which allows spoil or topsoil to be placed as required. Shifting the conveyor does take time, and most operations attempt to schedule a conveyor move once for every two pit widths.

5.3 SUMMARY

Strip mining is a type of surface mining in which overburden is removed in narrow bands, one cut at a time, and includes area mining and contour mining. The latter may be sub-divided into: (1) conventional contour mining method; (2) slope reduction method; (3) box-cut method; (4) head of hollow fill method; (5) block-cut method; and (6) mountain-top removal method.

Equipment selected for mining must be capable of excavation, transport, and placement of materials at lowest possible cost. Additional requirements brought about by new regulations pose considerable problems for the existing mine operator. New mines can plan equipment needs based on current information and requirements. Nature of overburden, life and production rate of the operation, geology, size and distribution of the mineral deposit, topography, legislation, and end land use must all be considered in planning equipment needs.

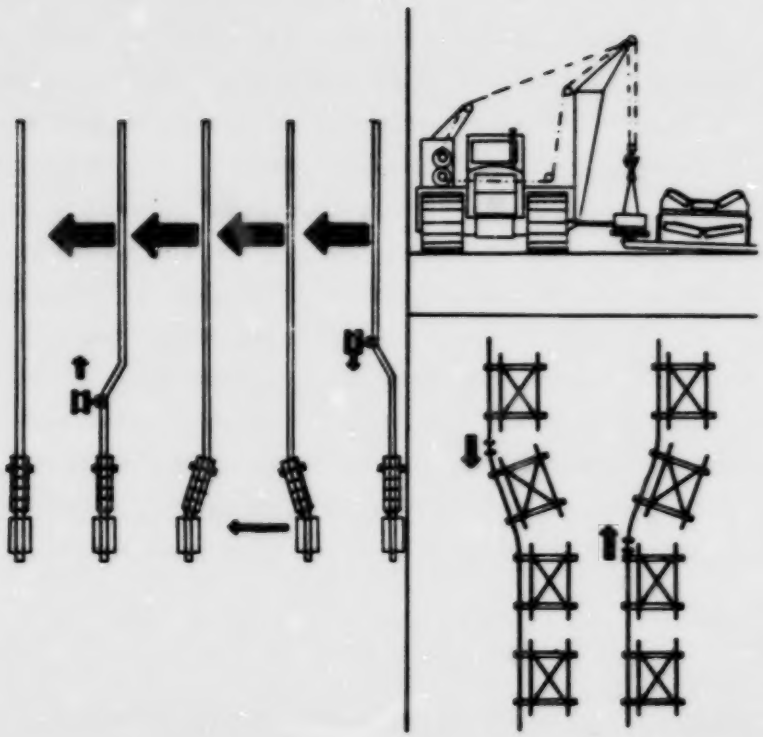

Figure 5.10 Shiftable conveyor system.

Source: Chopiuk and Chekerda (1982).

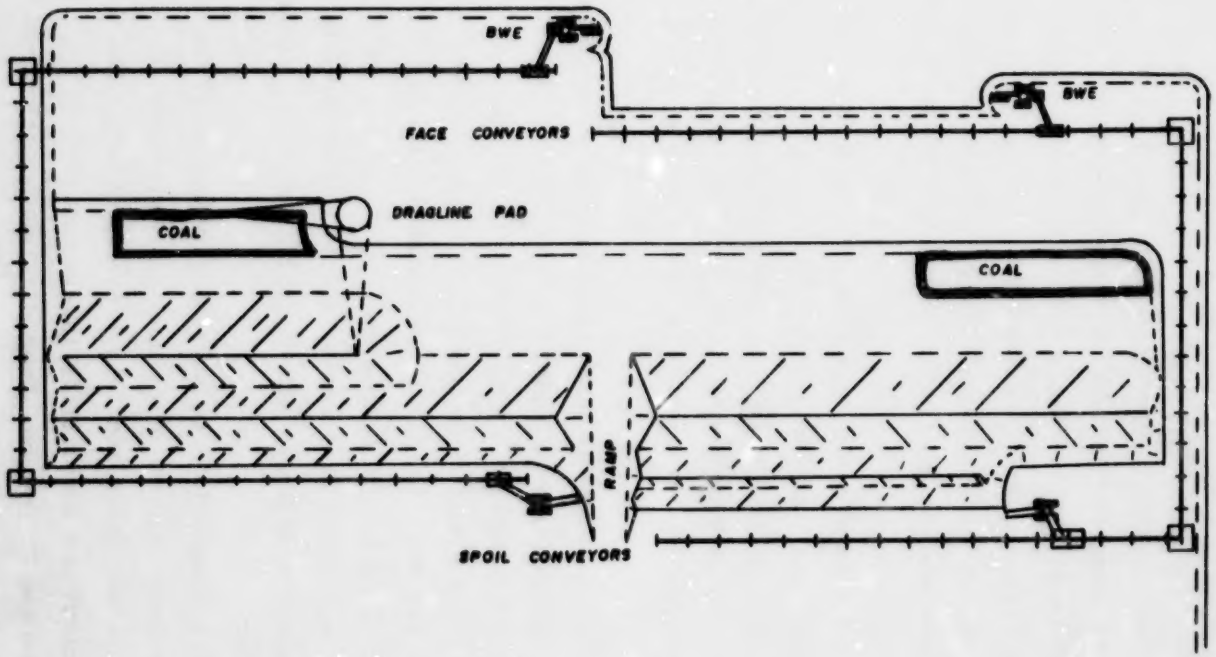

Figure 5.11 Twin system shiftable conveyor.

Source: Chopiuk and Chekerda (1982).

Draglines are cost efficient at moving and placing overburden. However, they are less efficient in terms of selective separation and placement of materials.

Dragline size must be selected to serve specific pit requirements. Use of twin dragline systems overcomes some problems, however, some potentially practical solutions are not feasible because equipment is not available (e.g., long-boom draglines).

Scrapers are used for road construction, grading, coal cleaning and partial removal, removal and stockpiling of topsoil, and recontouring spoil piles.

The capability of scrapers for selective materials handling is very good. However, weather and spoil/soil condition (texture, moisture) can seriously affect the scraper operation. Scrapers are highly mobile, but back up equipment and large fleets can cause on site congestion. Scrapers also cause compaction, which can be a serious problem in wet or fine textured soil.

Truck/loader and truck/shovel operations can be used quite effectively for removal and selective placement of materials. Because trucks have many specialized designs, flexibility in planning is increased. Shovels and loaders must be matched to trucks. Loaders are job-versatile and highly mobile. They must be matched to required production. A variety of equipment is available.

Traction is a problem with loaders, operator training is critical, and loader production probably cannot match shovel production for machines of equal size.

Shovels tend to mix materials to a greater degree than loaders and digging below ground level is not practical. Shovels have faster loading time, greater break-out force and long life expectancy. Mobility is restricted (track-mounted) and versatility is limited.

Bucket wheel excavator use has been limited to oil sands operations in Canada. The large capital investment makes use of this machine for small operations (e.g., removing thin layers of materials) impractical.

The bucket wheel is smaller than a dragline of comparable capacity, it digs continuously and has reasonable ability for selective handling of material. The machine lacks versatility and mobility and hard material may be difficult to handle.

Cross pit conveyors are relatively new to the mining industry. They have the ability to transport material from one side of the pit to the other (highwall to spoil) utilizing a combined conveyor and loading system. Selective handling of material is possible. Round-pit shiftable conveyors provide a continuous length of conveyor along the highwall, a side conveyor and a conveyor on the spoil side running the length of the pit. The round-pit system is more flexible than the cross-pit but probability of breakdown is increased and pit access ramps are restricted.

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6. LAND RESTORATION

The following review is taken from Habeck and Staff (1975). Where other references were used they are cited.

Proper mining practices and planning of spoil deposition can greatly enhance the efficiency and success of reclamation work; for instance, narrow mining pits reduce the amount of grading required, and toxic material can be deeply buried near the bottom of a spoil pile. Heights of the spoil piles can be controlled by planning of entrance roads and by gradual changes in grade by the equipment operator.

For the most part, the equipment used for surface mining is also used in reclamation. In addition, some mines use their own improvisations such as a harrow device made from a discarded track belt or a dozer towed to smooth the land.

Equipment used in building haul roads, such as motor graders and small front-end loaders equipped with a back-hoe, can also perform final grading and ditching work. Motor graders have the speed, mobility, and precise blade control for final grading and ditch excavation. These six-wheeled vehicles usually come equipped with a power shift transmission and the blade may be raised and lowered, tilted, sideshifted, and pitched to the side. Graders can also be equipped with dozer-style blades and scarifiers.

Small front-end loaders equipped with a rear-mounted back-hoe or bulldozer back-hoes are useful machines for trenching and small excavating jobs; they can cut and fill trenches, and construct silt traps.

In surface mining using bucket wheel excavators and stripping shovels together, spoiled rock is placed at the bottom of the pit after the coal has been excavated and is then covered by spoiled soil. This can be easily spread and contoured by dozers. The method has the advantage of covering potentially toxic rock materials and avoiding the peaks and valleys created by draglines or shovels.

With modern reclamation plans often requiring the replacement of soil over spoil material, scrapers are finding wide use in removing, stockpiling, and respreading soils and other unconsolidated materials

with few rock particles. Given adequate stockpiling room, scrapers can build separate piles for topsoil, subsoil, and other fine materials and then replace the materials evenly in the original natural layers.

Haul trucks are also used for this work, but are less effective since they must be loaded, travel more slowly, and cannot spread the topsoil as well as a scraper.

One experimental piece of reclamation equipment consists of a 62 t, twin-engine scraper with a large grader-type moldboard slung under the frame in place of the usual scraper pan. Other manufacturers have experimented with large, side by side crawler tractors, synchronized by one set of controls and pushing an oversized blade.

Three tools in combination with conventional bulldozers have proved cost efficient in shaping and leveling area-mined spoil banks (Goris and Howland 1976; Howland 1973). A large modified dozer blade (the "Big Dude") has been tested in the Midwest. This piece of equipment uses high volume lateral relocation dirt moving blades. The 12.2 m angle blade averages between 4590 and 4973 bank m^3 hourly using 795 net flywheel hp in the "push" and "tow" tractors. A 7.3 m vee plow has demonstrated an earth moving potential of 6120 to 7650 bank m^3 hourly in topping out area-mined spoil banks. A 7.3 m grading bar has proved effective in smoothing the shaped land.

Habeck and Staff (1975) have pointed out a need for more experimentation with conveyors for topsoil reclamation work. Previous success has been limited due to tearing of the belts at the loading point caused by sharp rocks. Better classification of conveyed material could alleviate this problem.

Track-type bulldozers are normally used for striking off the peaks of the ungraded spoil piles, although a small dragline may sometimes be used for this rough grading operation. Because the natural angle of repose of the spoil and the unconsolidated material creates steep slopes, wheel-type vehicles usually cannot be used for this work.

Reclamation requirements are very similar to those of road building and other large dirt moving construction work. It is therefore reasonable to contract portions or all of the reclamation work to dirt

moving contractors who have experience and know-how in moving mass quantities of soil. These contractors are also highly competitive in their field. Bid estimating for reclamation work does not have to consider all the unknowns that are common to construction work since the spoil has been handled once, during mining, and there should be very few surprises (e.g. rock ledges). Also, the spoil is unconsolidated and usually easily accessible so that large machines with high horsepower can be used to their maximum capability.

Much research is being done, especially in the west, to utilize tractors in surface preparation of leveled spoil material for runoff control and improved revegetation. Scarifiers and deep chisels are being used to break up compacted earth for better root penetration and to leave small scale contour furrows for moisture retention and erosion control. A prototype, tractor-drawn gouging machine is also being evaluated in cutting offset furrows for moisture retention. However, where slopes do not exceed 8°, surface preparation can usually be accomplished by conventional agricultural equipment, thereby freeing the huge tractive power of bulldozers for tougher jobs.

Ohio state law prohibits rocks over 20 cm in diameter on the surface of land that has been prepared for seeding. These rocks are currently being picked up by hand. A rock picker manufactured by Arnor Metal Products was tried but its bin of 2240 kg capacity was found to be too small for the job. A scraper with spikes welded 17.8 cm on centres along the cutting edge was also tried to lift out the rocks but the welded spikes frequently broke off. This is an instance where the surface coal mining industry needs help from equipment manufacturers to develop a rock picker suitable for actual conditions encountered during reclamation of mined lands.

Regrading has several purposes that may include aesthetic improvement of the land surface, returning the land to use, providing a suitable base for revegetation, burial of pollution forming materials, erosion control, drainage control, hazard reduction (high walls or deep pits and ponds), and control of water pollution.

Regrading should be performed in conjunction with spoil segregation, burial of pollution forming material, spreading of topsoil and other amendments, construction of water diversion facilities, and revegetation (U.S. Environmental Protection Agency 1973).

The U.S. Environmental Protection Agency (1973) has defined a number of regrading methods. These are described as follows:

Contour regrading is regrading to the original land contour. It is most effective and aesthetically pleasing but very expensive. It provides for reduction of the size of the disturbed area, reduction in erosion and water pollution, and deep burial of pollution-forming materials.

Terrace regrading and pasture regrading are similar in appearance and provide similar degrees of pollution control. These techniques create a gently sloping bench over a strip mine cut and a steep outslope beyond the mined area. Less earthmoving is required than in contour regrading but more than in swale regrading (below). A large disturbed area is created and erosion and landslides may be a problem on steep highwalls and steep outslopes.

Swale regrading creates a reverse terrace slope over a strip mine cut, a steep outslope beyond the mined area, and an exposed upper highwall. Swale regrading includes the Georgia V-Ditch, Swallow Tail and Reverse Terrace Rounding of spoil piles [see Habeck and Staff (1975) for pictorial description]. Much of the spoil is left in its original position. The effectiveness of Swale regrading depends upon a dense revegetation cover, proper location of swales, proper design of swale gradients, and burial of pollution-forming materials.

Area Contour Regrading is the regrading of spoil ridges and valleys to the original contours. Land is returned to a configuration useful for agriculture, silviculture, development, and recreation. The effectiveness of this type of regrading depends upon the establishment of vegetation and the runoff characteristics of the regraded surface.

Open - Pit Regrading is the stabilization of steep slopes, backfill of mill tailings or overburden, and regrading of soil on disturbed areas. A limited amount of regrading is possible, especially

where most of the material had been removed from the mine site, as in metal mines or quarries.

Highwall Reduction is slope angle reduction by removal of the top edge of the high wall (by means of grading or blasting) and is applicable to terrace, swale or open pit reclamation.

The following is provided as an overview of equipment used in revegetation following final grading of spoiled areas. More detailed information on equipment and methods is provided in the Sections VI, X and XI.

The following is quoted directly from Habeck and Staff (1975:131-132):

"Surface manipulation methods to increase survival rates in revegetation efforts, to prevent soil erosion and to conserve soil moisture in arid regions have received considerable attention over the past few years. Fresh spoil is very susceptible to compaction by earthmoving equipment and young plant roots cannot readily penetrate dense soils. Also, a cloddy seed-bed is needed to provide a range of seeding depths for better survival of broadcast seeds. Tractor-drawn deep chisels, disc harrows, and scarifiers can be used to loosen the compacted top...[15 to 20 cm] of spoil. Pulling these tools along the contours of the area creates small furrows which aid in moisture retention and erosion prevention. Agricultural tractors can be used on slopes up to 20%; steeper terrain requires the use of earthmoving tractors or graders which can manoeuver on slopes of up to 40% grade.

"Stairstep-sized contour terraces have been effective in promoting stabilization of ground cover. The horizontal ledges catch seed, fertilizer, and runoff which provide an initial growth, spreading over the slope naturally. Telescoping yardarms, equipped with scarifying tools, could be mounted on grading machines to shape these small terraces, but no such equipment is presently available as standard equipment.

"Research is being conducted on surface manipulation techniques for moisture retention in arid regions at a western mine. A prototype, tractor-drawn gouging tool digs small basins...[0.9 to 1.2 m] long and

...[15 to 20 cm] deep. Larger basins up to...[7.6 m] long and ...[0.9 to 1.2 m] deep are excavated by bulldozer. These techniques are presently being evaluated.

"Soil supplements, such as fertilizers, neutralizing agents, and mulches can be sprayed pneumatically or hydraulically over the surface or spread by ground roving machinery.

"Trailer mounted pneumatic spreaders can spray baled or bulk material up to...[24.4 m] from the trailer, under calm wind conditions. A separate tank and pump can add asphalt or other mulch "tack" at the spray nozzle and extension hoses can be connected to extend the reach and cover otherwise inaccessible areas.

"Hydromulchers or hydroseeders are large trailer or truck mounted tanks which can spray slurries up to...[61 m] under calm conditions. Slurry materials include seeds, sprigs, fertilizers, neutralizing agents, and various mulches. The materials are kept in suspension by a mechanical agitator in the tank and sprayed by a slurry pump capable of passing...[2.5 cm] solids through a turret-mounted nozzle on the top of the tank. Extension hoses can be added and "tack" material can be injected at the spray nozzle. A ripper is often installed at the feed hopper to break up baled wood fibre mulches....

"Seed is either broadcast over the ground or sown at a predetermined depth by seed drills. Broadcasting can be done by hand, pneumatic sprayer, hydroseeder, ground roving spreader or aircraft. Broadcast seeders are rather simple machines consisting of a hopper, feeding device and distributing wheels, and can be attached to the end gate of a truck, pulled by a tractor or mounted on an aircraft.

"Truck mounted or tractor drawn models have the higher capacities, while hand and aircraft seeding can reach remote or inaccessible areas. Airplane seeding, however, requires ground spotters to insure uniform coverage and is very dependent on wind conditions. This equipment can also be used to spread granulated or powdered fertilizers and neutralizing agents.

"Seed drills come in various configurations and allow seed to be planted at proper depths and covered in one operation. A hoe or disc

opens each of the furrows. An adjustable fluted cylinder or double-disc device controls the feeding of the seed into the furrow. The furrows are covered either by a set of dragged chains or by press wheels.

"Seedlings are usually planted by hand, but a mechanical planting system is currently being developed to plant seedlings grown in wire reinforced plastic tubes. An auger drill digs the holes and the tubelings are dropped in."

6.1 SUMMARY

Proper mining practices and planning are essential for reclamation. For the most part, the equipment used for surface mining is also used in reclamation. Modern day reclamation plans require selective handling of material; therefore, efficient use of properly designed equipment is essential. As a result, more specialized equipment is being developed or existing equipment modified for specific jobs.

Regrading of spoil/soil materials has several purposes, including aesthetics, specific land use, providing a suitable base for revegetation, burial of problem wastes, erosion control, drainage control, hazard reduction, and control of water pollution. A number of regrading methods have been defined, including:

1. Contour regrading -- regrading to original land contour.
2. Terrace regrading and -- create a gently sloping bench over a
3. pasture regrading strip mine cut and a steep outslope.
4. Swale regrading -- creates a reverse terrace slope, steep outslope, and an exposed highwall.
5. Area contour regrading -- regrading of spoil ridges and valleys to original contour.

6. Open-pit regrading -- stabilization of steep slopes, backfill of mine tailings or overburden, and regrading of spoil on disturbed areas.

7. Highwall reduction -- slope angle reduction by removal of the top edge of the highwall.

Once spoil regrading is completed, surface manipulation is often required to increase survival rates in revegatation, to prevent soil erosion, and to conserve soil moisture. This area has received considerable attention recently and is covered in detail in Sections VI, X and XI.

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SECTION III
REMOTE SENSING
APPLICATIONS IN RECLAMATION

7. REMOTE SENSING APPLICATIONS IN RECLAMATION

Maps are essential in planning and implementing any course of action on land. For most mining operations the course of action includes the planning, active, and cleanup stages. Each stage requires plans based on surface and profile descriptions of the site. The surficial description consists of maps prepared from survey data obtained in various ways, such as aerial photography, or remote sensing from airborne vehicles and satellites. This section is concerned primarily with remote sensing methods of obtaining survey information.

Remote sensing, defined in its broadest sense, is reconnaissance at a distance. The purpose of remote sensing is to measure environmental properties and phenomena without physical contact between the measuring devices and the objects (or phenomena) being examined. Remote sensing devices include, but are not limited to: (1) cameras, (2) thermal infrared scanners, (3) radar transmitters and receivers, (4) laser, (5) radio, and (6) sonar equipment. Remote sensor platforms include both aircraft and satellites. Cox and Witter (1978) have provided an excellent review of the applications of remote sensing technology to disturbed lands.

Remote sensors can provide timely and accurate information on the status of surface mining operations and reclamation progress, coal mine refuse piles and slurry ponds, acid water and siltation problems, and various aspects of environmental impact (Amato et al. 1975). Depending upon the accuracy requirements of various user agencies, these data are available through both low and high level aircraft surveys as well as LANDSAT imagery. SKYLAB imagery is available for May 1973 to February 1974. With two concurrently-orbiting earth resources satellites (LANDSAT 1 and 2) providing repetitive coverage every nine days, the potential exists for providing mining-environmental data to state, provincial, and federal agencies in a timely manner.

The Earth Satellite Corporation (1971) noted that remote sensing can provide data useful for: (1) inventorying the location and affected acreage of mined land; (2) planning reclamation of an area to be

surface mined; (3) evaluating the ecological effects of mining; and (4) monitoring the success of mined land revegetation.

They gathered data from the literature and conducted a series of interviews, producing the following list of information needs in reclaiming coal mines for which remote sensing imagery could most likely provide identifiable signatures to:

1. inventory the extent of disturbance and classify mined lands;
2. develop a land reclamation plan for post-reclamation users;
3. survey the area to be mined and subsequently reclaimed;
4. determine plant response following reclamation revegetation;
5. protect and monitor regional water quality;
6. determine the nature of mined area spoil primarily for regrading and revegetation and following revegetation;
7. determine the composition of mine area spoil prior to regrading; and
8. determine the moisture-holding properties of mined area spoil.
9. To determine the extent to which raw spoil or revegetated areas are subject to erosion or have already been eroded.
10. To determine the nature of the surface to be cleared and reclaimed.
11. To facilitate reclamation backfill and grading operations in mined areas.
12. To reduce and predict areas of slope instability.

Cox and Witter (1978) reviewed several studies that described the use of LANDSAT imagery for mapping lands and natural resources. Some purposes mentioned were detecting abandoned mines, acid mine water pollution, power plant site selection and power corridors, and understanding the interactions between land use and water quality. They noted that repetitive coverage, with the corresponding data extraction from the acquired imagery by skilled interpreters, may prove particularly

useful for providing government and the mining industry with information for meeting reclamation objectives.

Darden (1971:33-34) listed the following mapping requirements for creating a clear reclamation plan:

"1. A clear and comprehensive title block....
   (1) company's correct name
   (2) permit number
   (3) county and city of operation...
   (5) surface acreage affected by direct mining and related operations...
   (7) scale of map (a scale large enough to properly represent the area and to be easily measured and accurate enough for map calculations should be used). No map smaller than 8-½" x 11" in size will be acceptable.
   (8) ownership of the mining property, noting if it is leased, fee simple, etc., should be indicated....

2. A legend of symbols shall identify all features shown on the map. Map symbols, as noted in the Rules of the Surface Mined Land Use Board, must be used on all maps. Standard map symbols not so noted may be used when needed.

3. A north arrow that is clearly defined and pointing toward magnetic or true north and to the top of the map....

5. Bearings and distances of specific land divisions will be shown. Bearings and distances of the active mining area, spoil dumps, stockpile areas, plant sites, tailings ponds and any other area of affected land will be noted. Bearing and distance from reference points tied into the property boundary survey and lines to areas of affected lands will be noted....

7. The entire mined and affected area will be shown whether it be a quarry, borrow pit, sand pit, kaolin mine, etc. Areas of active mining, inactive or abandonment, will be noted by shading, identifying by year. All areas affected

will be identified by coloring red. Direction of proposed advancement will be noted by arrows pointing in the direction of advancement. Bearings and distances are essential.

8. Areas stripped will be clearly defined and treated as affected area. Bearings and distances relative to the stripped area will be noted. Overburden and waste areas must be defined and bearings and distance noted. Tailings ponds and other bodies of waters related to the mining operation must be defined and tied by bearing and distances to the property survey. Areas proposed for reclamation will be defined and associated bearing and distances shown. These areas will be identified by green shading.
9. All rivers, lakes, ponds, creeks and drainage will be noted within the map body and properly identified....

"In essence, a mined land use map illustrates current use of a production site by the mining operator and clearly depicts land use during and following mining activities. It reflects like a mirror a clear, sharp, concise image of mining and reclamation activities in a given area. Finally, the map will present the exact action that a mining operator intends to take on lands to be mined and reclaimed. A land reclamation map, therefore, is simply a specialized planning map...."

Omodt, Schroer and Patterson (1975) discussed the place of mapping in reclamation planning and monitoring. They found that the soil map is essential to determine (1) the soil resources of the permit area, and (2) the relative ease or difficulty of reclamation of the area. Assistance in selecting mining areas on the basis of the soil resources of the entire block could be the greatest value of the soil map. The soil map could be used to determine soil areas with ample amounts of suitable material with soil areas having limited amounts of material suitable for reclamation, thus improving the overall reclamation of the entire area.

A soils map should be based upon the properties significant to reclamation in the permit area including: (1) the soil properties and the range of soil properties of the material suitable for plant growth, (2) the ranges of soil properties of the soil material suitable for placement on the surface of the area to be reclaimed, (3) the amount of material having each of these two ranges of significant soil properties, and (4) the location of the soil material having these ranges of significant soil properties. Significant soil properties will vary with the kinds of soils within a permit area and in different permit areas.

Schafer (1979:1211-1212) has noted that "differences in the pattern of soil variability on mined land and natural landscapes affects how these soils can be mapped. On natural landscapes, soil maps can be prepared at varying levels of intensity and can consist of several different types of mapping units....The distribution of natural soils is related to geomorphic position, regional geology, climate, and other broad geographic factors. For this reason, individual soil series can be mapped with order 1 (1:10,000 scale) or order 2 (10,000-30,000) surveys...while distinct combinations of soil series or soil families can be mapped with lower intensity surveys (order 3-5). On mined land, soils are not correlated with landscape position. In addition, large contiguous mine areas are uncommon. Therefore, minesoils can only be mapped appropriately with order 1 or order 2 surveys."

Amato et al. (1975) published a table of the uses of different scales of imagery for identifying some mine land features (Table 7.1). From their review of the literature they concluded that LANDSAT data was better for regions with area mining rather than contour mining because of resolution problems. LANDSAT imagery gave limited discrimination of such features as mined land versus other vegetative stripping. But freshly stripped, non-mined areas and one or two classes of reclamation could be readily distinguished. SKYLAB photographs were useful for mapping vegetation in reclaimed areas, and for cultural detail or matching to topographic base maps. Air photos gave greater resolution and were good for mapping reclamation progress. But 1:120 000-scale photos are not

Table 7.1. Utility of different scales of imagery for effective identification of selected mined-land features.

MINED-LANDS INFORMATION CATEGORY	PLATFORM AND IMAGE SCALE					
	AIRCRAFT				SATELLITE	
	LARGE SCALE		SMALL SCALE		SKYLAB	LANDSAT
	1:10,000	1:20,000	1:60,000	1:120,000	1:500,000	1:1,000,000
MINING FEATURES						
DISTURBED AREAS	———	———	———	———	— — — —	
LARGE WATER IMPOUNDMENTS AND SLURRY/SLUDGE PONDS	———	———	———	———	— — — — — — —	
GOB/REFUSE PILES						
- Large	———	———	———	———	— — — — — — —	
- Small	———	———	———	— — — — —		
TYPE AND STATUS OF MINING						
- Area vs. Contour	———	———	———	———	— — — — — — — —	
- Active vs. Inactive	———	———	———	— — — — —		
BENCHES vs. SPOIL SLOPES	———	———	———	— — — — —		
ACCESS (HAUL) ROADS	———	———	———	— — — — — — — — —		
CULTURAL FEATURES	———	———	———	— — — — —		
- Railroads						
- Deep Shaft Entrances						
- Tipples						
- Plants						
- Buildings						
- Equipment						
HIGHWALLS	———	———	———	———	— — — — — — —	
HYDROLOGICAL FEATURES	— ———	———	———	— — —		
- Diversion ditches, outfalls, seepages						
ENGINEERING COMPUTATIONS						
- Overburden	— ———	———	———	— — —		
- Stock Piles	— ———	———	———	— —		
- Road Grades	— ———	———	———	— — —		

LEGEND:

——— GENERALLY USEFUL; REQUIRES SKILLED IMAGE ANALYSTS TO ACQUIRE MOST USEFUL RESULTS.

— — — USEFUL WITH DIFFICULTY.

Source: Amato et al. (1975).

useful for such detail as individual trees or acid mine drainage. Large scale photos are useful for detailed reclamation assessment (Table 7.2).

Deely, Russell and Wobber (1973) compared the use of satellite, high-altitude aerial photography, and low-altitude aerial photography for surveying disturbed areas. In Table 7.3, they show the effects of the various types of remote sensors on image resolution and image size.

Hughes et al. (1975) compared the resolution capabilities of ERTS, U-2, SKYLAB, NASA 1:25 000, and SCS 1:20 000 photos for detection of various reclamation features (Table 7.4). They found the NASA and SCS flights gave the most information followed by U-2, SKYLAB, and ERTS data.

Jaques (1977) discussed three points that determine the type and accuracy of a monitoring system for a given study:

1. Selection of an optimum film-filter combination or scanner band width. Filters are used to narrow the range of sensitivity. The spectral response of the subject(s) determine what film and filter combination will provide the best differentiation of the subjects.
2. Scale requires careful consideration. A large scale will allow for resolution of details; a smaller scale will make spatial relationships and surface patterns identifiable.
3. Cost is a major factor when selecting both of the above.

Jaques (1977) noted the importance of vegetation in monitoring and the fact that spectral properties of plants are well known on a morphological and anatomical level. Within chloroplasts, grana selectively scatter visible light while chlorophyll types and amounts within the grana selectively absorb visible radiation. The phenology of the plant affects its spectral response. Therefore remote sensing systems that provide maximum information on plants are very valuable.

Most sensors and scales allow for resolution of groups of plants only and, therefore, the group relationship of plants determines the visible image characteristic for each minimal resolution element. These energy/ecosystem relationships are not well understood at this time and require further study.

Table 7.2 Utility as to scale of remote sensors used for analysis of mine subsidence.

Sensor Data Used	Usable Scales	Utility	Optimum Season
LANDSAT-1 imagery	1:1 000 000 to 1:250 000	Detection of regional Lineament and Fault patterns	Various; Band 5, 7 Spring, Autumn
SLAR imagery	1:500 000 to 1:100 000	Fracture detection	Various; Spring, Winter, Autumn
Small scale photography	1:130 000 to 1:90 000	Detection of Fracture traces and regional subsidence	Early Spring
Colour Infrared (IR) photography	1:30 000 to 1:130 000	Detection of regional subsidence, fracture traces and pothole subsidence	Spring
Colour photography	1:30 000 to 1:130 000	Detection of regional subsidence and fracture traces	Spring
Panchromatic, colour IR, colour aerial photography	1:16 000 to 1:30 000	Detection of regional subsidence, fracture traces, and linear subsidence (extension)	Late Winter, Spring
Panchromatic, colour, colour IR aerial photography	1:10 000 to 1:16 000	Detection of pothole subsidence, linear subsidence, fracture traces, regional subsidence, environmental impact analysis	Late Winter; Early Spring
Thermal imagery	1:20 000 to 1:10 000	Regional subsidence detection	Spring

Source: Amato et al. (1975)

Table 7.3. Tabulation of image/photographic parameters as affected by scale change.

SCALE RATIO	1:1 000 000	1:120 000	1:60 000	1:20 000
Type of imagery or photography	LANDSAT Satellite Imagery	Small Scale High Altitude Aerial Photography		Large Scale Low Altitude Aerial Photography
Resolution limit	50 to 80 m[a]	5 m	2.4 m	1 m
Ground distance of 1 cm on image or photo	25 390 m	3 048 m	15 240 m	509 m
Ground coverage on 23 x 23 cm image or photo	3 425 259 ha	75 272 ha	18 652 ha	2 104 ha
Number of 1:20 000 aerial photos needed for stereo coverage of ground area	5 776	129	32	3

Source: Adapted from Deely, Russell, and Wobber (1973:23) and Alberta Remote Sensing Center (pers. comm.).

[a] Resolution or normal contrast targets is about 80 m.

Table 7.4. Resolution capabilities of five remote sensing vehicles for use in strip mine reclamation studies.

Reclamation Characteristic	ERTS	U-2[a]	SKY LAB[b]	NASA 1:25 000[c]	SCS 1:20 000
Areal Extent of Mining	X[d]	X	X	X	X
Age of Spoils		X	X	X	X
% Vegetal Cover on Spoils		X		X	X
Slope Angle of Spoils		X		X	X
Erosion (Rill and Gully)				X	X
Sedimentation		X	X	X	X
Reclamation Practices		X		X	X

Source: Adapted from Hughes et al. (1975).

[a] U-2 Colour Infra-red-Scale, 1:130 000

[b] Sky Lab-Black and White Multi-bank-Scale, 1:500 000

[c] NASA-Infra-red Aerial Photo-Scale, 1:25 000

[d] X denotes sufficient resolution to measure the characteristic.

7.1 AIR PHOTOS IN MAPPING

Deely, Russell and Wobber (1973) have discussed the uses and applications of both high-altitude and low-altitude aerial photography to reclamation work. The following summary is taken from their paper (Deely, Russell and Wobber 1973:19).

"The acquisition of high altitude photography at scales smaller than 1:60,000 acquired with high quality (6 inch [15 cm] focal length) lenses, is the result of relatively recent technological developments in aircraft design. Such photography has proven particularly useful for regional mined lands disturbance inventories. These inventories can be accomplished in any detail consistent with selected film type and photographic scale. Small scale aerial photographs have been rectified and used as a photographic map base corresponding to the standard $7\frac{1}{2}$ min quadrangle configuration. If photographic parallax distortions are not objectionable, such bases are superior in information content to standard planimetric or topographic maps.

"The resolution of high altitude aircraft photography permits mapping with greater accuracies than does ERTS imagery. Mine land boundary detail is more distinct and more quantitative as well as qualitative data can be derived. The advantage of repetitive cover provided by ERTS-1 cannot, however, be easily duplicated using high altitude aircraft.

"At present, commercial acquisition of photography at scale ratios smaller than 1:80,000 is not practical, and most photography available at scales of 1:80,000-1:120,000 has been acquired by NASA or other government agencies. Colour infrared film appears to be the best photographic media for the majority of applications but further investigations using multiband coverage are required. The false color rendition of this film is rarely a hindrance in analysis and usually is an asset.

"The special qualities of this film for vegetation discrimination is particularly useful in evaluating the success of

revegetation efforts. Grass cover can generally be separated from tree cover and estimates of plant cover versus bare ground can be made.

"The type and degree of grading for reclamation purposes is apparent and haulage roads can be distinguished from contour benches. Refuse piles and slurry ponds only a few tens of feet in diameter are mappable from small scale, color infrared photography. Heavy stream sedimentation, high turbidity, and iron oxide discoloration in water can be identified in streams and ponds over 30 feet [9.1 m] across. All but the smallest areas of highwall slumping, spoil bands and landslides are readily identifiable at these smaller scales.

"Small scale, color infrared photography has proven useful in identifying large areas of stressed vegetation resulting from poor soil fertility and/or high acid content. This application applies largely to areas seeded to grass rather than trees. Tree spacing and plant size in the first 7-10 years of growth is such that judgements of plant condition and survival percentages from aerial photography are impractical except for very large scale images. However, as the current trend in reclamation is to grasses rather than trees, small scale color infrared photography should increasingly prove of value for monitoring revegetation progress....

"Black and white, low altitude (large scale) aerial photography has been used operationally for many years by both mining companies and state regulatory agencies for routine data acquisition in mined areas. Mining companies chart the progress of their mining operations, compute overburden and stock pile volumes, layout access roads, loading facilities, drainage control, plan stripping and reclamation operations. Black and white aerial photography is often used as field reference maps, and as an operating and recording base.

"Large scale aerial photography is used selectively by the mining community, and is most often acquired only over those specific active mine sites where a maximum quantity of information can be obtained most practically by photogrammetric means.

"Large scale natural color and color infrared aerial photography has not been used extensively as a source of mined-lands

information largely because of higher acquisition costs. Additional skill may be required for interpretation even though color photography can provide significantly more hydrological information, particularly in relation to surface water quality, vegetation, and spoil characteristics. Surface water turbidity, relative mine water depth, presence of clay suspensions, iron oxide deposits in lake and pond bottoms and stream beds, acid seeps and outfalls, stream sedimentation patterns, and surface and flood plain sediment deposition, spoil types (which have characteristic colors permitting their identification) within bare or predominantly bare surface mined areas can be readily identified. When used in conjunction with available stratigraphic and lithologic data, the interpretation of surface spoil types and their locations can lead to identification of acid and/or toxic surface spoil materials.

"Color infrared (false color) aerial photography has proven particularly superior for derivation of information related to vegetation. Vegetation types, species, percent cover and condition of vegetation have been interpreted reliably in mined areas. Species interpretations, even though compounded by exotic species plantings common in reclamation operations, can be made when analysts have access to industry and state reclamation records and selectively field check test areas. Color infrared photography permits early identification of vegetal stress that may be caused by adverse environmental conditions such as spoil toxicity, moisture and/or nutrient deficiency, acidity or sedimentation effects both within and near mined areas.

"The better rendition of vegetation detail, plus superior haze penetration capabilities of color infrared photography, permits the interpretation of more environmental and reclamation-related information at substantially smaller scales and higher altitudes than with either black and white or color aerial photography."

Amato et al. (1975) found small scale (1:120 000) colour infrared photography (NASA) very valuable for assessing problems on mined land with sufficient accuracy for most users. The film provides adequate resolution for the detection of moderate contrast targets in

excess of 5 to 10 m although those of 10 to 15 m are more usually mapped. Mapping units of 2+ ha are practical, although smaller units are possible. Data may be mapped and presented on 1:24 000 scale base maps. Regrading and vegetation cover can be readily assessed although individual tree sets cannot be identified.

The colour rendition of the 1:120 000 scale infrared photography provides an added dimension and interpretation from the film and is judged to be as accurate as that attained on 1:80 000 panchromatic photography.

Downing (1971) noted that under normal ground conditions it is cheaper to use ground survey methods than photogrammetric methods. He mentioned previous work in 1969 which quoted 5 ha as the point at which aerial survey may start to be cheaper than field survey work. Downing, however, found that the break-even point was considerably higher than 5 ha. In the case of highly contorted disturbed land, the figure may well be below this amount for a ground survey involving a great deal of time to obtain the required number of levels. Downing pointed out that many variables, plus changing costs for labour and machine operations, make general statements of comparative costs somewhat meaningless.

According to the literature, relatively large-scale imagery obtained from aircraft at comparatively low altitudes is most applicable to detailed study of the features of smaller land areas.

In east Tennessee, a study by Tschantz (1973) used three sets of low-altitude (1:12 000 scale) colour infrared photographs plus 1:120 000 scale high-altitude photos. Thermal imagery contrasted strip-mined and non strip-mined areas. The pre-leafing season was best for monitoring slide activity. Cost of producing the maps was about $0.25/ha.

More recently, Spisz (1978) published a study to illustrate the use of an 11-band multispectral airborne scanner to describe the land cover features of an abandoned coal mine in Ohio. The study area included extensive benches and spoil banks of very toxic sandstone and shale.

The multispectral scanner measures reflected solar energy in seven visible wavelength bands and three near-infrared wavelength bands with silicon detectors. It also measured the emitted thermal energy from the earth's surface in the 11- to 14-micrometer atmospheric window band with a liquid-nitrogen-cooled mercury-cadmium-tellurium detector. The aircraft was flown at an altitude of 1.2 km.

The data were analyzed by computer, forming 29 classes of which 12 were land-cover classes and 17 were barren land types. Resolution of the scanner was 3 m at 1.2 km making this system much more accurate than LANDSAT data with a resolution of 57 m x 79 m.

Spisz (1978) found that the 3 m spatial resolution of the data that corresponds to the 1.2 km aircraft altitude was suitable for selecting good training sites for analyzing the barren land areas and was more than adequate for studying the undisturbed pasture and forested areas. In fact, aircraft altitudes in excess of 3 km with 7.5 m spatial resolution would have been acceptable. The 3 m spatial resolution, however, was marginal for studying impounded-water areas and was totally inadequate for analyzing streams and drainage ways. It was recommended that 1.5 m resolution be used for future studies of impounded-water areas and that less than 1 m resolution be used for analyzing streams and drainage ways. Spisz also found that a September run produced better results than a March run due to an overcast sky and surface dampness in the spring.

Suchecki and Evans (1979) used air photos and on-site reconnaissance to delineate five major biotic communities, including an abandoned surface mine area, on a proposed surface mining site in Indiana. The purpose of the study was to determine wildlife information which would aid in reclaiming the disturbed areas later.

The Earth Satellite Corporation (1971) conducted a survey of individuals using remote sensing data in reclamation activities in the United States. Included in the survey were details on scale and applications of the resulting data. The reader is encouraged to obtain the report for more information.

In Great Britain, Gibson (1974), Bush (1972), Collins (1972), and Collins and Bush (1971), have applied aerial photography to the acquisition and monitoring of derelict land information. Gibson (1974) described the use of 1:5000 scale black and white air photos and supporting data such as geological maps and land use maps to map derelict land in a county in Wales. It was possible to map and inventory many derelict land types, including buildings. A similar study by Bush (1972) and Collins and Bush (1971) described the use of standard air photos of a scale of 1:10 500 to inventory and map 36 types of derelict land in a 200 km^2 area of Yorkshire. Included were: (1) lands disturbed by coal mining, (2) sand and gravel extraction, (3) brick works, (4) power stations, and (5) sewage plants. Both of the above papers indicated that mapping and inventory by air photo was inexpensive, rapid, and accurate. Gibson (1974) noted that the photographs provided enough detail for features to be identified in both urban and rural environments, however the small scale (1:5000) required nearly 6000 photographs to cover the county. Both authors stressed the need for coupling air photo interpretation with ground truthing to provide up to date and accurate information.

Collins (1972) referred to some of the air photo studies in Britain including the study of Bush (1972) and summarized some of the problems and advantages of remote sensing by air photography. He pointed out that sometimes it is difficult to determine if a site is active or abandoned. Air photos are better than field surveys for drawing the gradational boundaries of derelict land. Better overall detail is provided than by field survey and the work is 10 times faster. In addition, the data have utility for other correlative social and economic studies.

7.2 SATELLITE IMAGERY IN MAPPING

Deely, Russell and Wobber (1973) have reviewed the applications of satellite imagery and aerial photography to remote sensing of mined lands. They found that multiband imagery from the Earth Resources Technology Satellite (ERTS), with its 18 day repetitive

coverage, has practical applications to mined land inventory and monitoring. ERTS acquires imagery simultaneously from four spectral bands: green (0.5 to 0.6 um); red (0.6 to 0.7 um); near infrared (0.7 to 0.8 um); and, near infrared (0.8 to 1.1 um). Generally, resolution of 100 m targets is possible; however, high contrast targets less than 80 m in diameter may be identified. Amato et al. (1975) noted that this makes use of satellite data better for area mining sites as opposed to contour mining sites.

The contribution of the green spectral band appears to be small due to diffusion of shorter wavelength light by the atmosphere. Of the infrared bands, the 0.8 to 1.1 um band provides increased contrast of land versus water and bare ground versus vegetation. This band is considered the most useful for mined lands studies. Recombining bands using additive colour techniques increases water and vegetation discrimination.

Identification and mapping of area and contour surface mining is possible, dependent on the contrast between mined land and the surrounding vegetation. Discrimination decreases as revegetation improves. Resolution generally allows positioning on U.S. Geological Survey base maps (1:250 000).

ERTS imagery allows gross estimates of revegetation of disturbed lands. Refuse piles and slurry ponds can be identified on high-quality imagery if the long dimension is at least 1.6 km. Water bodies, generally elongated on surface mined land, can be identified if widths are at least 30.5 m. Marked contrasts in water colour allow some identification of water quality, using colour additive techniques, for smaller water bodies (less than 213 m long).

Amato et al. (1975:315) were somewhat less optimistic as to the monitoring capabilities of satellite imagery. They noted that "at present, it appears that for most state requirements for around-the-year, surface mined land monitoring, LANDSAT, or imagery of comparable resolutions, is of limited value. Not only are most of the necessary judgements of mine land status difficult or impossible to make on the best quality of such imagery, but, in many parts of the United States

the acquisition of cloud free imagery is uncertain. However, for periodic, e.g., yearly updating of regional surface mine maps, LANDSAT can provide information rapidly and economically for updating progress of new mining and reclamation of mined land."

Cox and Witter (1978:714) reviewed the applications of remote sensing technology to disturbed lands. They found the advantages of satellite data were: "...(i) a near orthographic view, (ii) large aerial coverage and regional perspective, (iii) multispectral capabilities, (iv) temporal coverage, and (v) reduced effects of handling low altitude aerial data (for large areas). The main disadvantage...[was] lack of resolution."

Several studies have been conducted using satellite data to delineate mine sites and reclamation activity in Canada, the U.S., and elsewhere.

Murray (1977) published a discussion of a Canadian mine waste inventory derived from LANDSAT imagery. The inventory covered mines having significant production prior to 1974 and some recent developments in selected areas. Seven hundred and eighteen mines, identified as having ore reserves plus ore production to date (1977) amounting to 2 242 000 t and waste dumps greater than 10 ha, were recorded.

Contrast of spectral signatures, and geometric and interpretive limitations in the LANDSAT data restricted the inventory to areas greater than one hectare. Accuracy of measurement depended on signature contrast. For areas less than about 8 ha, accuracy varied between ±5 and ±30 percent. Although tailings, slag, overburden, rock waste, water, and vegetation were usually distinguishable, they may be confused with some materials of non-mining origin. Heavy vegetation commonly obscures the material it covers. Waste rock may be confused with ore stockpiles or with rock outcrops. Configuration of surfaces was difficult to assess from the data used in the inventory and more detailed topographic information could be obtained from aerial photographs. Separation of natural vegetation from revegetation depends largely on cultivation patterns or supplementary information.

Jaques (1977) used LANDSAT data to assess vegetation in Alberta, including disturbed areas. He found that coal spoils have very low reflectance values in infrared bands and relatively high reflectance (low absorption) in the red band. Spoils of different ages could be discerned in the subalpine regions of the province (Figure 7.1). The author was also able to detect differences between grasses used in reclamation at the McIntyre coal mine near Grande Cache and surrounding natural plant associations, especially in bands 5, 6, and 7.

Jaques (1977:26) noted that the advantages of LANDSAT digital data over conventional photography were: "(1) an image of any one site can be obtained every nine days (assuming no cloud cover); (2) a 400 mi^2 [1036 km^2] area could be studied and mapped with less than 1/15 the amount of labour; and (3) the cost of the LANDSAT imagery would be $200 compared to $2 500 for 1:60 000 scale colour-infrared imagery. The disadvantages of LANDSAT imagery were: (1) that it takes highly specialized training for a researcher to be able to analyze the digital data; (2) sophisticated computer equipment is necessary to analyse the LANDSAT imagery to get ...[these] kinds of results...; and (3) the resolution of LANDSAT picture cells (pixels) are 0.44 hectares in size."

A study of 30 coal strip mining sites in Wyoming, Montana, and North Dakota, using LANDSAT data and supervised computer classification was reported by the U.S. Environmental Protection Agency (1975). Active mining areas, graded spoils areas, ungraded spoils piles, revegetated spoils piles or areas, and such other features as roads, ponds, and cropland were successfully classified. LANDSAT data was useful only on mines with homogeneous areas greater than about 200 x 340 m. Significant variations between mines and even for the same mine meant that the classification algorithm had to be calibrated for each site. Accuracy depended on available ground data for training. Where natural vegetation was sparse, it was difficult to separate undisturbed areas from revegetated areas. It was also difficult to distinguish mined areas from fallow or eroded crop land.

In Indiana, Russell et al. (1973) made an early attempt to evaluate LANDSAT imagery for monitoring surface mining operations. The

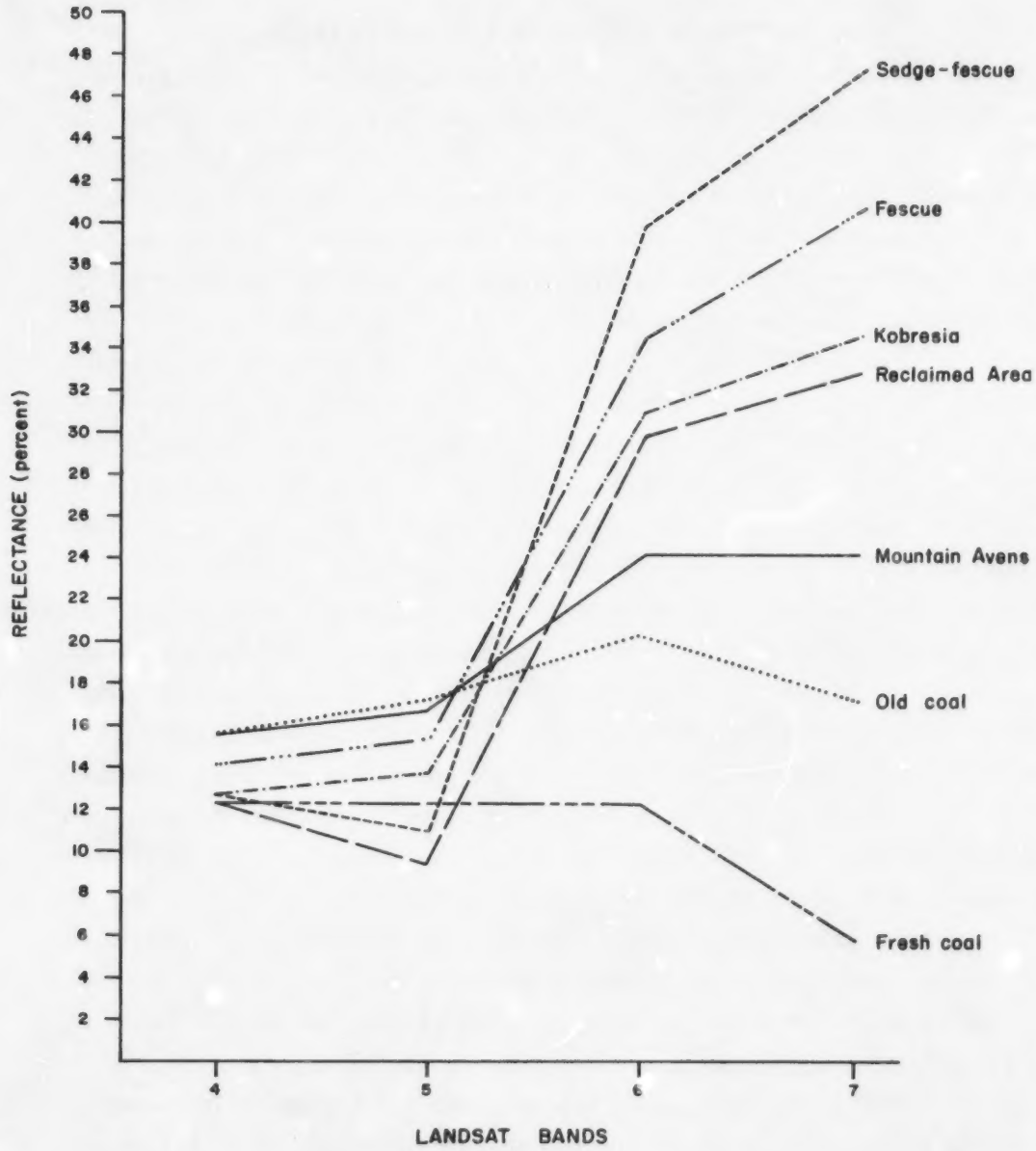

Figure 7.1. LANDSAT radiometric values of vegetation types in the alpine-subalpine region of the northern Rocky Mountains, Alberta. July 26, 1975 image.

Source: Jaques (1977)

utility of the various multispectral scanner bands in identifying mined landscape features is indicated in Table 7.5. Band 7, for summer imagery, was best for delineation of mined lands, assessing reclamation through vegetative cover, and mapping sizes and shapes of water bodies. The contrast in near infrared reflectance between bare ground and vegetation permitted identification of disturbances as small as 4.1 ha. They also found that colour composites could be used for the above information plus band 4 to assess water discolouration and turbidity.

Borden, Thompson and Lachowski (1973) reported on an early study to map coal mining refuse in Pennsylvania using ERTS data collected in October 1972. They identified 42 signatures, the most important of which were: (1) refuse and silt, (2) clear water, (3) muddy water, (4) swamp vegetation, and (5) an anomaly, which was surmised to be burning refuse. There were some difficulties in separating coal refuse and strip mine spoils; however, comparison of maps generated by the satellite data and U.S. Geological Survey data showed close correlation.

Alexander, Dein and Gold (1973) reported on an early application of digital LANDSAT data to monitor the aerial extent of coal mine stripping in Pennsylvania, to detect areas adversely affected by acid mine drainage, and to assess the effectiveness of reclamation and pollution abatement procedures. They used the unsupervised spectral clustering approach on data from bands 4, 5, and 7 in September 1972. They were able to delineate stripped areas and subcategories (trenches, backfills) as well as vegetation affected by acid mine drainage. This could not be done visually using LANDSAT imagery. They noted that the spectral response of several stripped areas in different locations was similar, suggesting that these characteristic signatures could be used to obtain accurate maps of existing mines and refuse piles over larger areas (e.g., state, region).

An early study by Chase and Pettyjohn (1973) dealt with mapping strip-mined land and reclamation progress using LANDSAT data. Visual and computer techniques (Bendix system) were employed. They were able to map disturbed lands with both methods but at the time (1973)

Table 7.5. Merits of four spectral bands and a colour composite from LANDSAT Imagery for reclamation work.

ERTS MSS SPECTRAL BAND	4	5	6	7	Colour Composite
Fracture Detection		xx	x	x	x
Mined Land Delineation			x	xx	x
Reclamation (vegetal cover)		x	x	xx	xx
Water Bodies (size and shape)		x	x	xx	x
Water Discolouration and Turbidity	xx				xx
Physiographic Features		x	x	xx	xx

Source: Adapted from Russell et al. (1973).
[a] Subjective evaluation: x = fair to good, xx = good to excellent capability.

were still working on more detailed mapping of reclamation and could not express an opinion as to their success. They found that strip-mines had such a distinctive shape that they could be identified without other graphic aids (photos or maps). Best results were found in band 5, followed by 6 and 7, then band 4. Standing water was best seen in bands 6 or 7.

Rogers and Pettyjohn (1975) used the Bendix multispectral data analysing system to demonstrate the capability of LANDSAT 1 to map strip-mining and reclamation in Ohio. They found that mapping accuracy was about 90 percent. A supervised classification system was used to establish map categories including stripped earth, partially reclaimed earth, natural vegetation, and water. The accuracies of these categories were 96, 98, 92 and 100 percent, respectively. They concluded that strip mining and reclamation mapping costs using LANDSAT would be about 10 percent of conventional mapping costs. Furthermore, LANDSAT mapping is much faster and can easily be done repeatedly.

Also in Ohio, Ahmad, Katner and Antalovich (1973) used LANDSAT black and white prints, on a scale of 1:1 000 000, from four multispectral scanning bands in an attempt to map reclaimed and unreclaimed strip mined areas and undisturbed lands. They were able to map large areas of unreclaimed stripped land but not reclaimed areas. Water bodies showed up best on infrared (band 7) as did coal piles. Vegetation showed on bands 5 and 7 though the authors did not study these areas thoroughly.

Anderson and Schubert (1976) reported on a test in Virginia of three techniques using LANDSAT data. These were visual analysis of enlarged LANDSAT band 7 photos, computer analysis with the ERTS system, and computer analysis with identification of spectral clusters. Both computer methods were shown to be valuable for setting up data bases for land use planning in addition to mapping and monitoring strip-mine reclamation. The computer methods produced more detailed analyses than did visual methods. The LARSYS2 multispectral clustering method could distinguish 12 vegetation-soil-water types in the study area.

Anderson et al. (1976, 1977) assessed the effectiveness of two digital analysis methods to delineate strip-mine regions in Maryland from LANDSAT data. Their first method was a four-band analysis distinguishing various strip-mine-associated classes and conditions. This method proved useful but had limited extendibility over a seasonal or annual period.

In the second approach, a band-ratio method was developed to measure disturbed surface areas, and it proved to be extendible both temporally and geographically. This method was used to measure area changes in the region over three time periods from September 1972 through July 1974 and to map the entire two-county area for 1973. For mines ranging between 12 and 98 ha, the measurement accuracy of total affected acreage was determined to be 92%. Mines of 50 ha and larger were measured with greater accuracy, some within one percent of the actual area.

Amato et al. (1975) compared SKYLAB and LANDSAT data from strip-mined areas in Indiana and Kentucky. They found that with LANDSAT imagery it was difficult to discriminate between land disturbed by actual mining and that disturbed by other associated activities, particularly the systematic removal of vegetation and topsoil in advance of actual stripping operations. In addition, partially revegetated mine spoil had a reflective character intermediate between bare rock and undisturbed land while land reseeded to grasses had reflective properties much like the natural terrain.

SKYLAB data at a scale of 1:250 000 distinguished strip-mined land from land recently reclaimed (within five years) but could not distinguish older reclaimed areas. Changes as small as 1 ha could be detected in areas of high to medium contrast. Analysis of black and white S-190B enlargements (1:100 000 scale) indicated that nearly all past and current reclaimed areas, if covered with less than 75% vegetation, could be accurately delineated. One or two classes of reclamation assessment could be detected. The 1:100 000 scale provides adequate resolution for positioning the mine boundaries on existing base maps. Mined areas could be readily delineated at 1:24 000 (especially

where high contrast existed between freshly mined soil and rocks and the much darker surrounding vegetation); however, the resolution of the enlargement at this scale was not adequate to produce the detail and accuracy required by some government agency needs. At this scale, mined areas could be delineated with a tolerance of ±17 m, compared to ±60 m in areas of lower contrast such as reclaimed land.

Amato et al. (1975) concluded that once an accurate data base has been established from aerial photography, high quality LANDSAT imagery, enlarged to scales as much as 1:100 000, could be used on a regional basis if accuracy requirements were not stringent. Repetitive imagery with resolution approximating the S-190B camera would provide significantly superior data for monitoring mining and reclamation activities.

Using LANDSAT band 5 imagery, Seevers, Lewis and Drew (1975) mapped erosion blowouts in sand hills and areas of low vegetative cover in a large area of stabilized sand dunes in Nebraska. They successfully mapped blowouts 1 to 50 ha in size and potential blowout areas with vegetative cover less than 10 percent. Band 5 appeared to provide the best data for identifying the blowout areas.

Gilbertson (1973a, b) described applications of LANDSAT data to reclamation in northeastern South Africa. The objective was to detect and monitor vegetative cover on mine dumps. He was able to visually detect six cover classes of vegetation on one date of observation using bands 4, 5, and 7 in a colour composite;

"1. No vegetation cover;
2. A very small plant community, usually constantly 'farmed' by fertilizing, water spraying and 'ploughing';
3. A poor cover of plants requiring continuous attention. Extensive 'soil' exposure;
4. A reasonable cover of vegetation requiring occasional attention and fertilizing with a number of 'soil' exposures on small areas of high acidity;

5. A good cover of vegetation, probably self-sustaining, with only a few 'soil' exposures on small areas of locally high acidity;
6. A probably self-sustaining plant and tree community over 100% of the dump surface." (Gilbertson 1973a:581).

Comparison of LANDSAT data with aerial photographs showed that all large mine dumps were detected on the ERTS-1 image. Furthermore, there was a good qualitative relationship between the six vegetation categories on the ERTS-1 image and actual ground readings. The more densely vegetated dumps were darker on the image than the unvegetated dumps.

Densiometric measurements on a 1:160 000 scale black and white negative allowed differentiation of some vegetation categories (0, 1, 4, 5) but some anomalies were present. The author noted that two plots registered densities which seemed anomalous given their location. It was discovered, however, that the two areas had been subjected to irrigation prior to the photos being taken which changed their reflectance by producing an increase in vegetative growth. From this experience, Gilbertson (1973a, b) stressed the need to know information on previous husbandry practices during image interpretation.

7.3 NUMERICAL ANALYSES FOR REMOTE SENSING

Cox and Witter (1978), in their review of the applications of remote sensing to disturbed land studies, discussed the analysis of digital data. They noted that until recently, imagery was organized and classified by manual methods (visual interpretation). However, modern technology has led to the development of numerical analyses using the spectral variations recorded in a digital format. These techniques are especially applicable where large digital data sets are available (e.g., from scanner systems) or where several bands of multispectral data are analysed simultaneously. Various systems exist which allow an investigator to process digital data to identify spectral signatures and display and record features of interest. Statistics and analog data can then be used to produce photographic products.

A number of techniques may be applied to imagery to make interpretations easier. For example, optical enhancement, including additive colour processing of multiband imagery, contrast stretching, density slicing, and enlargement (photographically, or image magnification) can be used.

Digital data, extracted from imagery or magnetic tapes in a variety of formats, are often initially displayed as shaded computer printouts using conventional printing devices. Data may also be displayed on a cathode ray tube as shades of gray or colour-coded. Special equipment may be used to print the colour-coded data.

The objective of either process is to provide a more easily interpretable product than the original. Photolab-type enhancements are generally less expensive than digital techniques; however, both increase analysis costs and should be evaluated for cost effectiveness.

Several of the studies in the previous sections used computer analysis to enhance the data generated by LANDSAT. The following papers deal with specific computer programs for use in reclamation work.

Anderson and Schubert (1976) have described the use of two computerized techniques for evaluating data from LANDSAT images. ERTS Analysis is a system utilizing point-by-point digital analysis of spectral signatures based on known spectral values. LARSYS2 uses a clustering technique on combined data from bands 5 and 7 to generate spectrally separable clusters. Further information on methodology may be obtained from their paper.

The use of ground photography plus data from standard topographic maps to portray the impact of proposed industrial developments on the landscape was described by Entzminger (1976). Terrain data, digitized and stored in a computer, were used to produce a drawn overlay of the intended development on the oblique photograph using a program called MOSAIC. The technique is low cost, accurate, requires a minimum of special skills, equipment and data, and portrays the visual impact of the proposed development on the landscape. It is particularly applicable to the planning and reclamation aspects of many kinds of industrial developments.

An application of computer graphics called ECOSITE was described by Mallary (1977). ECOSITE was under development in 1977 to design aesthetic land forms for reclamation in surface mined areas. It has the capacity of generating a set of land forms and to modify the composition by alternative approaches. It can both represent the design and output images in various ways. Finally, it can test the design for a variety of requirement such as resistance to erosion.

Yamamoto (1975) studied the use of trend surface analysis to represent regional topographic distinctions, variations, and characteristics in the pre-mining stage. The purpose was to aid in the return of topography after mining, for aesthetic value and such factors as surface and subsurface hydrology. An example was given where the first, second, and third degree equations explained 25, 32 and 60% of the topographic variation of a certain site, illustrating an instance where the third degree equation would be chosen because it best fitted the original land form. However, such factors as spoil variation, climate, and vegetation must also be taken into account.

7.4 REMOTE SENSING TO ASSESS RECLAMATION SUCCESS

Jaques (1977) used LANDSAT data to assess vegetation in Alberta. He found that moist sites reclaimed with Melilotus spp., Medicago sativa, Trifolium pratense, Bromus inermis var. inermis, and Agrostis alba showed very high reflectance in both infrared bands because of the dense herbaceous vegetation cover (Figure 7.2). Heavy growth of native plants contributed significantly to the observed response on favourable (moist) growing sites. Dry site reclamation activity with the same species was less successful and its reflectance was lower in the infrared bands than was the moist site reclamation and natural bog complex vegetation.

Chase and PettyJohn (1973) found reclamation mapping in Ohio much more complex than disruption (disturbed versus undisturbed) mapping. The difficulty arose when attempting to assess degree of reclamation in percentage cover. One problem encountered was the variety of vegetation used in reclamation (e.g., Vicia spp., Pinus spp.,

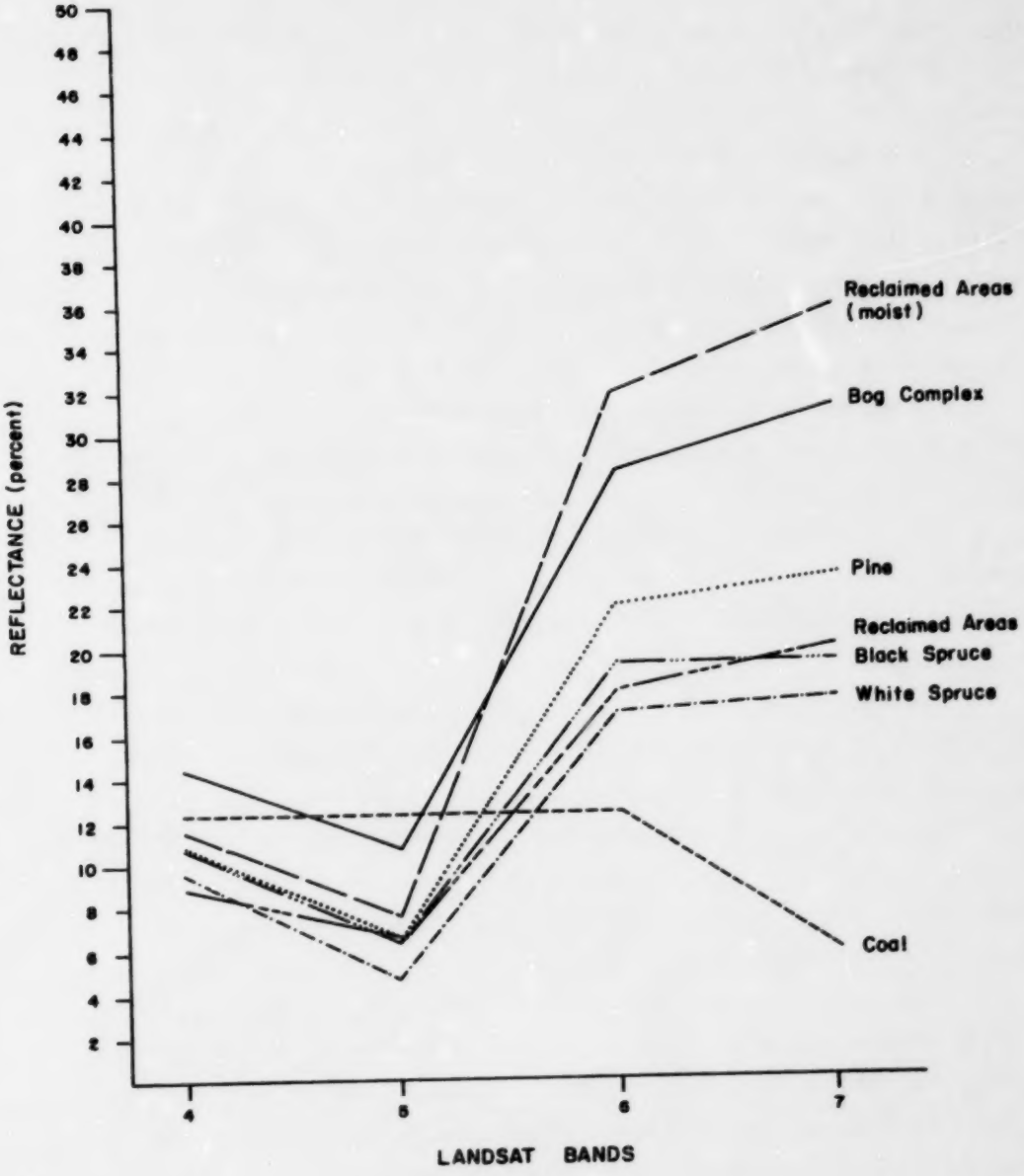

Figure 7.2. LANDSAT radiometric values of vegetation types in the boreal forest of Alberta. August 4, 1974 image.

Source: Jaques (1977)

Robinia pseudoacacia) in addition to natural recolonization. The authors indicated the need for further work on image enhancement of reclaimed areas.

Ahmad, Katner and Antalovich (1973) found that reclaimed strip-mine areas were the most difficult areas to distinguish on ERTS-1 pictures. They noted that reclaimed areas, planted to grass, showed slightly darker on bands 4 and 5 and a little lighter on infrared (band 7). On older sites in Ohio (reclaimed 20 to 30 years earlier with trees) the task was much simpler.

Anderson and Schubert (1976) found that reclaimed areas in Maryland and West Virginia which had been planted to grass less than two years previously were difficult to distinguish from recently seeded areas. They noted this problem was due to two factors: (1) the spoil in the reclaimed areas contained a high degree of carbonaceous material mixed into the original soil cover, and (2) the grass was not dense enough to change the spectral response.

Russell et al. (1973) also used high altitude colour infrared photography to monitor surface mining operations in southwest Indiana. In addition to successfully mapping landscape features as small as 4.1 ha, they were able to map reclamation success as percent of ground cover from LANDSAT band 7, by determining changes in albedo. This is in contrast to a lack of success reported in some other studies. The reasons for their success were not given.

Deely, Russell and Wobber (1973) also found that gross estimates of the amount of revegetation of disturbed lands can be made by analyzing changes in tonal character of mined land on band 7 images.

In Alabama, where diverse methods of mining had been used, Hughes et al. (1975) studied two sites to evaluate the use of remote sensing in observing the effects of strip-mining. Since 1970, companies in Alabama have been required to grade mined lands to a rolling topography, cover toxic materials, divert water, reduce siltation, erosion or other damage, and seed or plant within three years after the permit expires. On the two sites under study, 57 and 38 percent of the disturbed land had been reclaimed since 1969 and before 1973, using

Pinus spp. seedlings. But by 1973, much of the evidence of reclamation was not visible on the photographs.

7.5 SUMMARY

Remote sensing can provide useful data for:

1. inventory of location and affected acreage of mined land;
2. planning reclamation of an area to be surface mined;
3. monitoring and evaluating the ecological effects of mining;
4. monitoring the success of mined land revegetation; and
5. mapping of critical pre-mining and post-mining features.

Mined land soils are not correlated with landscape position and large areas are uncommon. Therefore, greater resolution is required in utilizing remote sensing for mapping purposes.

Individual remote sensing techniques have uses applicable to specific situations. The end use of the imagery should, therefore, be carefully planned and appropriate technique(s) selected. Factors to consider in making the selection include film-filter combinations, scale, and cost.

Because of the importance of vegetation in reclamation and because the spectral properties of plants are well known on a morphological and anatomical level, remote sensing systems that provide maximum information on plants are very valuable. However, more information is required on the plant group relationships that effect the image characteristics of minimal resolution elements.

Technology has developed to the point where high altitude photography acquired with high quality lenses is very useful for mined lands disturbance inventories. Base maps superior in information content to standard planimetric or topographic maps can be produced. Accuracy is greater than for ERTS imagery, although the repetitive cover of ERTS cannot easily by reproduced. As well, commercial aquisition of small scale, high altitude photography may not be practical, or available.

Colour infrared film appears to be the best photographic media although multiband coverage warrants more research. The false colour rendition of infrared film is usually an asset and vegetation discrimination is particularly good. Many physical features and environmental effects can be readily identified and mapped. Identification of large areas of stressed vegetation (grass rather than trees) is possible. Superior haze penetration permits interpretation of more environmental and reclamation-related information at substantially smaller scales and higher altitudes than with either black and white or colour aerial photography. Colour infrared at 1:120 000 has been cited as equal or better than panchromatic photography at 1:80 000.

Large scale aerial photography is routinely used by mining companies where maximum information is required. Generally, black and white film is used as natural colour and colour infrared photography is too costly and additional skills are required for interpretation. However, colour photography can provide significantly more hydrologic data and colour infrared is particularly superior for obtaining detailed vegetation information.

Multispectral airborne scanners have been tested. This methodology provides data from seven visible and three near-infrared bands plus thermal imagery. Resolution is good to less than 3 m.

Five hectares has been cited as the point where aerial survey becomes cheaper than field survey, but this is not agreed upon and it has been suggested that the critical area size may be much greater than this. As well, comparison of costs may be meaningless because of changing labour and machinery costs and site specific conditions (e.g., topography). Low level photography is more efficient for small areas. In any event, air photos must be coupled with ground truthing for maximum accuracy.

Remote sensing from satellites has found considerable application in mapping. Three systems, ERTS, LANDSAT (four satellites), and SKYLAB have generated data. SKYLAB was a manned vehicle intermediate between satellite and high altitude photography.

Some users have questioned the value of satellite imagery. The method has several advantages: (1) it provides near orthographic view; (2) it provides large aereal coverage and regional perspective; (3) it has multispectral capability; (4) it provides temporal coverage; (5) it reduces the effects of handling of low altitude data; and, (6) costs per unit area are significantly lower than for aerial photography or ground survey. Disadvantages include: (1) lack of resolution; (2) highly specialized training required; (3) specialized equipment is needed to get detailed results; and, (4) cloud-free imagery is uncertain.

ERTS imagery provides resolution from 80 to 100 m although this is specific to the object in question. Four spectral bands were available. For mapping of mined land and reclamation the green band was found to be of least use and the infrared of most use because of land versus water and bareground versus vegetation contrasts. Additive colour techniques increase water quality and vegetation discrimination. As vegetation cover increases on reclaimed land, discrimination decreases. Resolution allows combination with 1:250 000 topographic maps.

LANDSAT resolution is restricted to features greater than 1 ha in area (although 0.44 ha was reported in one study). For areas less than 8 ha, delineation accuracy may be ±5 to 30%. The various LANDSAT spectral bands are quite specific in terms of optimum information use. Digital analysis of LANDSAT provides better resolution than visual interpretation and is often necessary to obtain results of required accuracy. Quite significant detail is possible; for example, Bendix multispectral analysis of LANDSAT has given 90+% accuracy. The larger and more homogeneous the area, the better the resolution and information retrievable. The efficiency of LANDSAT is improved if aerial photography data base is available. In any case, classification algorithms must be calibrated for each site. LANDSAT mapping costs are estimated at 10% of conventional methods, and are repeatable and faster.

Black and white LANDSAT photography at 1:100 000 has not proven useful for mapping reclaimed land. Confusion of natural land and

mined land is possible regardless of film. It is difficult to discriminate between land disturbed by mining and that disturbed by other activities, particularly removal of vegetation and topsoil ahead of mining. Vegetation obscures features and topography is difficult to delineate. Coal spoils have low reflectance in the infrared band and high reflectance in the red. Other reflective characteristics are often common to different types of terrain or disturbance, making separation difficult.

Differentiation of strip-mined land from recently (within five years) reclaimed land is possible with SKYLAB 1:250 000 photography. However, older reclaimed land is not distinguishable from natural areas. Black and white, 1:100 000 photography can be used to map nearly all past and current reclaimed areas, if less than 75% vegetated. At enlargement to 1:24 000 high contrast areas can be mapped to ±17 m tolerance; low contrast areas (e.g., reclaimed land) to ± 60 m tolerance.

Photographic and analysis technology associated with satellite imagery is constantly being improved. Therefore, the value of the technique to mining and reclamation planning will continue to improve.

Digital analysis is most applicable to large data sets or to simultaneous analysis of multispectral data sets.

Optical enhancement such as multiband imagery, contrast sketching, density slicing, and enlargement are available for improving interpretation.

Several computer programs have been generated specifically to handle and enhance data generated by satelite imagery. These include LARSYS 2, MOSAIC, ECOSITE and others.

Such analysis techniques increase costs and should be evaluated for cost effectiveness.

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SECTION IV

SPOIL AND SOIL PROPERTIES

Reclamation of disturbed lands has three objectives: (1) restoration or improvement of the aesthetic value of the landscape; (2) restoration of the utility of the land for human use to a level at least equal to the level of usefulness before disturbance; and (3) restoration in a manner which imparts permanency to the reclaimed condition.

Restoration of aesthetic value and utility for human use includes re-creation of suitable topography. Vegetation usually needs to be re-established to approach the natural near-climax ecosystem or a desired form that can be maintained indefinitely, preferably without human intervention. The environment for the desired ecosystem consists of chemical and physical factors, the characteristics of which depend upon the nature of the geological materials and how they have been disturbed. The new environment also depends upon the changes that will naturally occur in these materials after exposure to the atmospheric environment, and on the changes and amendments that man is able to impose on disturbed land.

The physical and chemical aspects of the new land surface environment may or may not change rapidly with exposure to weathering, and man may or may not be able to facilitate desired changes. Regarding the chemical aspects of the new environment, it is usually possible to correct deficiencies, for example, by fertilization; however, excesses such as elemental toxicities are less easily corrected.

The physical aspects of the new environment may be influenced by its chemical aspects, allowing some measure of control or correction through materials chemistry. Many physical aspects of disturbed lands are, however, difficult to manipulate. Soil texture for example, cannot be easily changed once a new surface material is placed. Thus, plant environment deficiencies related to soil physical properties must be avoided or corrected during soil reconstruction and recontouring.

8. HYDROLOGIC PROPERTIES OF SPOIL/SOIL

Land disturbances can alter surface and subsurface water hydrology by altering the magnitude of lateral surface and subsurface flows and vertical percolation and capillary uptake fluxes. Since land disturbances, especially mining, may markedly alter the soil and spoil biochemistry, marked changes in chemical quality of these water fluxes may also occur.

Changes in flux magnitude, chemical quality, and ground cover can cause changes in sediment loading or physical quality of these fluxes.

The nature of the hydrology in reclaimed spoils is usually such that once the materials are laid down and contoured little can be done that is economically feasible to correct hydrology problems. The emphasis then should be on preplanning materials handling and reclamation, and their effects on spoil hydrology. Two reports which illustrate the importance of this preplanning are reviewed below.

In Utah, Burton, Gifford and Hart (1978) studied the physio-chemical properties of tailings and spoils from 24 sites where metals, limestone, coal or clay were mined. Where the methods of materials handling and disposal were similar, surface hydrology was also similar. Improved hydrologic characteristics were obtained by segregating and using the higher quality overburden for revegetation, shaping spoils to topographic compatability with the surrounding area, mulching with organic matter, and minimizing compaction.

In a study in Arizona (Rodiek, Verma and Thames 1976) attempts were made to reclaim unsightly copper and gold mining spoils which were causing lake pollution. Methods used included: (1) recontouring, (2) revegetation, (3) drainage control, and (4) re-establishing the vegetation and landform aspects to conform with the undisturbed surrounding areas. The researchers found that total reclamation was not always possible or feasible and consequently utilization of the land for subsurface resource extraction might preclude or limit its subsequent utilization for surface land uses. Thus, Rodiek, Verma and Thames (1976) concluded that, contrary to earlier belief, utilization of surface and subsurface land resources did conflict with one another, and that

reclamation to resolve these conflicts must be planned before mining. In this experience, reclamation of highly toxic metals was unnecessarily expensive and technically difficult. They suggested that the research effort required to identify the problem and develop solutions would have been less and the chance of successful reclamation greater if reclamation had been planned before mining.

8.1 SURFACE WATERS

8.1.1 Surface Water Quantity

Of the various water inputs and outputs in the local hydrologic cycle, precipitation is probably little changed and with the exception of surface flow onto the area, incoming water quality is independent of mining activity. However, the portion of precipitation that becomes groundwater and surface water may be considerably altered by mining activity.

There are two major methods for disposal of excess surface water. It can be channeled or otherwise carried away by surface drainage or it can be otherwise diverted to groundwater. Downing (1971) discussed a situation in England where excess water at a mine site must be disposed of by surface drainage. The amount of drainage depended on soil conditions. On grassed areas, runoff was about 10% of rainfall, whereas on shale runoff may be 50 to 75% of rainfall. The paper describes the use of drains, settling ponds, diversions for water control, and the importance of protecting adjacent property. Site drainage must provide for the worst conditions expected, assuming a high runoff coefficient.

The severe erosion and sedimentation problems in the Swan Hills of Alberta is caused in part by inattention to proper runoff disposal (Wyldman 1971). Proper control and runoff disposal can be achieved by adequate diversions and culverts, proper site preparation, grass and legume revegetation, and fertilization.

The importance of controlling water at the source was stressed by Draskovic (1973). He stated that the objective should be to store as much water as possible in the overburden instead of attempting to control

it after it is lost as runoff. Similarly, surface manipulation experiments by Jensen and Hodder (1975) controlled and minimized surface runoff by increasing infiltration and percolation.

The hydrology of mined lands in the northern Great Plains is that of a moisture deficit climate with saline-prone soil and groundwater. Dollhopf, Jensen and Hodder (1977) reported that much of the limited rainfall on strip mined lands in Montana, North Dakota, and Wyoming is rapidly lost as runoff from the smoothed surface of recontoured terrain. In addition, during the winter, snow is blown from such smooth surfaces. Topsoiling and surface manipulation reduced surface runoff and enhanced moisture conservation by adsorbing and retaining moisture (Table 8.1).

In further descriptions of these and additional similar field and lysimeter experiments in North Dakota (Jensen and Schafer 1979; Jensen and Hodder 1975) nutrient and chemical runoff loading, moisture conservation, vegetation establishment, and equipment development for creating microrelief were discussed. Gouging conserved the most moisture and produced the most dense and productive vegetation stands, although seeding may be difficult. This is discussed in more detail in Chapter 15.

In more humid environments, such as eastern North America, moisture deficits are less of a concern and the potential environmental damage from surface runoff is primarily due to flooding and erosion.

In studies of the impact of surface mining on hydrology in Kentucky, Curtis (1977) reported that flow from a mined watershed was more variable than from an unmined watershed as the tendency was towards larger storm flows and lower base flows. In hydrologic terms, storm flow is the measured flow of surface water in streams or rivers during the storm event; base flow is measured between storm events. Storm flows are largely controlled by surface runoff while most of the base flow comes from groundwater discharge to springs and the stream bed. Strip mined watersheds in Indiana have increased base flow, apparently due to increased storage capacity in the saturated soil zones.

For example, in one storm in April 1977, flow from a mined watershed peaked about 10% lower than from an unmined watershed as more

Table 8.1. The effect of man-made microrelief and topsoiling on surface runoff from reclaimed land.

Microrelief[a]	Runoff cm	
	without topsoil	topsoil
chiselling	16.7	4.8
gouging	13.7	2.3
dozer basins	ND	1.6

Source: Dollhopf, Jensen and Hodder (1977).

[a] Chiselling to 30 cm depth, 30 cm spacing
Gouging to form pits 40 x 60 x 15 cm deep
Dozer basins 6 x 7.5 x 1 m deep

water went into storage in the mined watershed. Surface mining produces vast quantities of broken rock which can create a large underground storage capacity, thereby reducing surface runoff. The relationships between storm precipitation events, infiltration rates, and water erosion are discussed in detail in the next section and in Chapter 10.

8.1.2 Surface Water Quality

In arid climates, surface waters associated with strip mining are a valuable resource. On the northern Great Plains, impounded water on mine sites is useful for livestock or for irrigation (Gilley, Gee and Bauer 1976). However, they recommended that the chemistry of such impounded water should be determined before its utilization. Their analyses of surface waters at strip mines in the northern Great Plains showed that these waters may be unsuitable for livestock or irrigation (Table 8.2).

Jensen and Schafer (1979) found the concentrations of NO_3, Mg, Ca, soluble salts, and most trace elements were low in runoff water in the topsoiling and surface tests referred in Table 8.1. From the same experiments (Dollhopf, Jensen and Hodder 1977) concentrations of Mn and Fe were sometimes higher than federal standards for drinking water and occasionally Cd, Pb, and PO_4 were high.

In studies in North Dakota (Jensen and Schafer 1979; Jensen and Hodder 1975) effluent quality exceeded U.S. drinking water standards, with the exception of the levels of Mn and Fe as dissolved solids that were markedly elevated, primarily due to increased SO_4 levels.

Effluent concentrations changed relative to irrigation quality as follows: increasing sequentially in magnitude were SO_4, Ca, Mg, HCO_3, Cl_2, B, Mn, Ca, Fe, while Na, Zn, and NO_3 decreased.

Under even more arid conditions than that of the northern Great Plains, Thames, Patten and Crompton (1974) in Arizona found that total soluble salts in mined area runoff is higher than from natural areas (Table 8.3).

Considerably more research on the chemical quality of surface water has been undertaken in the humid climates of Europe and eastern

Table 8.2. Water quality of strip mine ponds in the northern Great Plains.

Parameter[a]	Units	Standards[b]		Water Quality[c]	
		Livestock	Irrigation	1975 11 14	1976 05 13
TDS	mg/L	2500	500.0	1420 to 3840	1190 to 4260
SAR		ND	6.0	5.1 to 12.2	6.8 to 21.1
EC	mmhos/cm	ND	7.5	1.3 to 3.3	ND
SO_4	mg/L	500	200.0	300 to 1460	260 to 1410
NO_3	mg/L	200	ND	1.0 to 3.3	ND
B	mg/L	ND	0.8	0.2 to 1.0	ND
Cl_2	mg/L	1500	100.0	5.0 to 17.0	3.6 to 14.0

Source: Adapted from Gilley, Gee and Bauer (1976).

[a] TDS: total dissolved solids
SAR: sodium adsorption ratio, concentrations in meq/L.
EC: electrical conductivity

[b] California state water quality control board, 1963.

[c] Range of values from seven strip mine locations.

Table 8.3. Runoff water quality in mined and natural watersheds in Arizona.

Quality Criteria: Chemical Species	Runoff Water (ppm)	
	Natural	Mined
soluble salts	177	310
Ca	24	41
Mg	3.6	13
Na	21	22
Cl_2	3.0	3.0
SO_4	65	100
HCO_3	3.0	3.0
HCO_3	0.0	0.0
F_2	0.2	0.3
NO_3	2.4	1.6
pH	7.6	7.4

Source: Thames, Patten, and Crompton (1974).

North America. Most reports indicated that the content of minerals or salts in drainage water is increased by mining. As previously noted, surface pond drainage can be enriched particularly in total dissolved solids, SO_4, Fe, and Mn, while some ionic loadings decrease (Jensen and Schafer 1979; Jensen and Hodder 1975). Dyer and Curtis (1977) found that peak flows of six first order streams in Kentucky increased three- to five-fold after surface mining. Changes in concentration of the major dissolved species, Ca, Mg, SO_4, and HCO_3, were inversely related to the log of the discharge. Thus, changes in chemical species concentration were less than changes in runoff magnitude while mining was ongoing. Following mining and backfilling, infiltration and moisture storage in the unsaturated soil zone is restored, lowering surface runoff and peak discharge. Thus once mining ceases, there is a slow return to normal in the hydrograph. Changes in water quality lag several months behind mining activity due to the time required for pyrite oxidation and water percolation through the spoil.

In Kentucky, Curtis (1973) found that mining increased total dissolved solids in runoff 13-fold due to pyrite oxidation and acid leaching. Pyrite oxidation and associated leaching can be controlled by segregating pyritic materials, maintaining the pit free of water, and backfilling and grading to maximize runoff and limit infiltration.

Plass (1975) reported water quality variations on four experimental watersheds in West Virginia. The levels of most dissolved species increased with mining. There was significant variation between growing and dormant seasons for all variables except SO_4 and Mn. Significant variation also occurred from year to year prior to mining. Plass et al. (1975) found it difficult to construct a model relating water flow to chemical reaction kinetics in a disturbed watershed. The difficulties stem from variations in spoil properties, unknown chemical reaction rates, and the unknown distribution of acid-producing potential between surface and groundwater flows. A static model, however, relating concentrations of certain water quality parameters to the physical and hydrological characteristics of the disturbed watershed, was successfully developed.

Minimization of mine drainage acidity can be related to surface regrading, filling subsided land, installing water conveyance structures, and revegetation (Dougherty and Holzen 1976). The most significant factor affecting acid load in this study in Pennsylvania was stream flow. Corrective measures were less effective due to extraneous factors such as industrial development and highway construction, although the net acid stream load was reduced by 43% from 1971 to 1975.

Some research has been done on fish and wildlife and their hydrologic requirements as a component of reclamation planning. Mine spoil surface ponds support aquatic life which may have recreational and environmental value. Brenner (1974) reported that in most strip mine pools in Pennsylvania, measurements of water chemistry and aquatic life, including plankton and fish growth, indicated a significant potential for recreational development.

Co-operation between mine operator, land-owner, and ecologist would facilitate reclamation for fish and wildlife. Conversely, Lewis (1977) reported the deterioration in water quality and biotic composition of an intermittent small stream in Arizona in response to a large sudden loading of liquid copper mine waste. Suspended solids settled out, coating the stream bed, altering its morphology, and ultimately lowering water quality and biotic diversity.

Physical quality or sediment load is usually closely and directly controlled by the quantity of surface runoff. It follows then that most surface erosion can be attributed to inadequate diversion or control of excessive surface water and subsequent runoff. Control of surface water and runoff was discussed in the preceeding section on surface water quantity.

Sedimentation is another undesirable effect of surface water flow and is closely linked with erosion and man's disturbance of the land. Draskovic (1973) stated that 50% of the sediment in one river in Yugoslavia comes from agricultural areas, 30% from forests, and only 20% from geological erosion. Much of the severe erosion and sedimentation problems in the Swan Hills is attributed to anthropogenic causes (Wyldman 1977). In south-western Kentucky, Curtis (1973) reported that the sediment source in

streams was primarily from spoils, haul roads, and the mines. All watersheds showed increases in suspended solids in runoff water during active mining though much of the sediment was trapped in weir basins. Davis and Hines (1973) in Kentucky stated that basins were used to control sediment from surface mining while the operation was underway and until recontouring and revegetation could effectively control erosion. Nawrocki and Vir Kathuria (1975) calculated the efficiencies of nine surface mine sedimentation ponds in Pennsylvania, West Virginia, and Kentucky. The efficiency is defined as the percentage of incoming suspended matter that has settled in the pond, calculated according to the following formula:

$$R = \left\{ \frac{\frac{10^6}{C_1} - 1}{\frac{10^6}{C_2}} \right\} 100$$

where C_1 is solids concentration of influent mg/L
C_2 is solids concentration of effluent mg/L
R is solids removed %

All of the efficiencies determined exceeded 90%. The authors found ponds constructed off natural waterways were more efficient than ponds built across natural waterways.

Kao, Lyons and Barfield (1976) studied the action of vegetation in controlling sediment using laboratory experiments with artificial materials, including glass bead experiments. They used various artificial grasses in a flume. In their literature review, they pointed out that Cynodon dactylon has been recommended for grass sediment filtration. In their flume experiments, they used the following equation to assess sediment filtration or retention:

$$\frac{S_i - S_s}{S_i} = \text{Exp}\left\{-1.05 \times 10^{-3}\left(\frac{VmRs}{Y}\right)^{0.82\left(\frac{WLc}{Q}\right)}\right\}$$

where S_i = inflow sediment concentration
S_s = outflow sediment concentration
Y = Kinematic viscosity
L_T = length of grass filter
w = fall velocity of sediment particle
Q = discharge into the channel
R_s = spacing hydraulic radius = $\frac{d_f d}{2d_f + d}$

where d = average spacing of the grass blades
d_f = depth of flow

Table 8.4 shows some of their results in terms of the distribution of different particle size fractions down the flume.

Kao, Lyons and Barfield (1976) found the degree of stiffness of the grass had limited effect on filtration capacity, although the more flexible grasses reduced the bedload storage capacity. Similarly, the slope had only a limited effect on filtration efficiency in so far as it influenced water flow velocity. Grasses were considered to be markedly efficient sediment filters, environmentally safe, economical, easily adapted to various site conditions, requiring minimal maintenance, and were particularly effective where the discharge rate or flow velocity was small and sediment concentration high.

Reflecting similar viewpoints, Grim and Hill (1974) recommended vegetated strips along stream banks and low stock pile and waste dump slopes.

8.2 SUBSURFACE WATERS

The primary concerns or impacts of land disturbance on subsurface water are chemical water quality and quantity, with most research emphasizing the former (Rogowski, Plonke and Broyan 1977; Van Voast, Hedges and Pagenkopf 1975). For example, Rogowski, Plonke and Broyan (1977)

Table 8.4. Sediment distribution according to particle size fraction with distance from sediment source down the flume.

Test	Sample Location (cm in grass)	Discharge (L/s)	Slope (%)	Flex.	Density No. of Blade/m^2	Particle Size Breakdown (% by Volume)						
						<0.6 mm	<0.5	<0.31	<0.21	<0.15	<0.10	<0.05
10	0.3	3.710	4.0	Stiff	13 175	29.9	48.3	13.2	8.6			
10	1.5	3.710	4.0	Stiff	13 175		22.0	42.0	23.5	9.5	2.7	0.3
10	2.7	3.710	4.0	Stiff	13 175			7.2	0	35.9	50.7	6.2
10	End	3.710	4.0	Stiff	13 175					32.1	39.4	8.5
19	0.3	3.512	4.0	Stiff	24 025	46.7	43.1	8.2	2.0			
19	1.5	3.512	4.0	Stiff	24 025			18.4	4.3	41.6	34.3	1.4
19	2.7	3.512	4.0	Stiff	24 025				4.4	30.2	61.9	3.5
19	End	3.512	4.0	Stiff	24 025					29.4	63.7	6.9
29	0.3	2.832	4.0	Med.	13 175	34.5	47.8	9.1	8.6			
29	1.5	2.832	4.0	Med.	13 175			22.4	27.9	20.3	26.3	3.1
29	2.7	2.832	4.0	Med.	13 175			15.4	36.0	19.2	26.3	3.1
29	End	2.832	4.0	Med.	13 175					38.5	57.0	4.5
42	0.3	3.129	4.0	Least	13 175	22.7	47.1	12.0	16.8	1.4		
42	1.5	3.129	4.0	Least	13 175			34.0	31.7	13.5	18.1	2.7
42	2.7	3.129	4.0	Least	13 175				15.6	30.3	44.0	10.1
42	End	3.129	4.0	Least	13 175					42.7	49.8	7.5

Source: Adapted from Kao, Lyons and Barfield (1976)

reviewed literature on the impact of strip mining and reclamation processes on groundwater. They found most studies dealt with revegetation and spoil placement for purposes such as minimizing acidity. Spoil gas, water content, and fluxes are ill defined; hence, the in situ rate-determining chemical processes are not well known. One such process, oxygen flux, is likely to differ considerably in spoil compared to natural soils. Since in situ spoil environments have not been quantified, little modelling has been attempted.

Moran, Groenewold and Cherry (1978) stated that the hydrology and geology of the surface and subsurface must be thoroughly documented before mining if the subsurface hydrology after mining and reclamation is to be projected. The relationships between the soil parent material and the surface and groundwaters should be known.

Gardiner and Woolhiser (1978) pointed out that surface and surbsurface water quality and movement must be understood in order to design techniques to establish vegetation, control erosion and pollution, and to stabilize spoils. This involves many aspects of the disturbed materials and topography including micro and regional climate.

In the Fort Union Coal Region of Montana, Van Voast, Hedges and Pagenkopf (1975) found the main hydrological effects of strip mining were changing groundwater patterns during mining and groundwater quality deterioration after mining.

8.2.1 Subsurface Water Quantity

Rahn (1975) observed that mine pits in Montana will be flooded or remain dry depending on the groundwater level. The spoils themselves may become man-made aquifers if they become saturated. This could be a beneficial, albeit inadvertent, side effect of strip mining. Where the climate is very dry and rainfall is far short of evaporation, as reported for Arizona by Verma, Thames and Patten (1975), there is no buildup of groundwater. In such areas, the serious soil moisture deficit greatly hampers revegetation of strip mined land.

Where climate is humid and rainfall exceeds evaporation as in eastern Canada and the U.S., much of the precipitation infiltrates and

reaches groundwater in strip mine areas. For example, in one eastern Pennsylvania watershed, disturbance increased infiltration from 25% to 60% of total precipitation (Pennington 1975). Concurrently, surface runoff was reduced from 25% to 10% and evapotranspiration increased from 25% to 30%. The inference was that under high rainfall (117 cm/yr in this study) regrading and planting can reduce water infiltration and acid mine drainage.

Van Voast, Hedges and Pagenkopf (1975) found that if the mine cut is backfilled, premining groundwater flows are likely to re-establish, although they may be more highly mineralized.

Carvallo, Gee and Bauer (1979) found that slope percentage, soil texture, bulk density, sodium adsorption ratio, and topsoiling influenced available soil moisture stored in mined and unmined soils. The relationship, however, between the soil characteristics and moisture storage were site specific. Gardner and Woolhiser (1978) indicated that conflicts may occur, for example where excessive water enters the groundwater system causing inadequate drainage. In this situation, surface drainage needs to be improved. However, this may be difficult to accomplish, after revegetation, without disturbing plant cover.

The effects of strip mining on depth to groundwater and quality of groundwater is of particular concern where water is used for livestock and domestic purposes. Van Voast (1974) found that the most marked lowering of groundwater levels by strip mining occurred in wells closest to the mine as the well recharge area had been cut off by the mine. He postulated that the degree to which below-ground hydrology will return to the premining condition depended on the condition of the area after mining. Recovery would be least if the final mining cut was left open, and greatest if the final cut was completely closed. In contrast, Van Voast, Hedges and McDermott (1976), reporting on mines in Montana where coal beds are commonly the aquifers for livestock and domestic water supplies, concluded, perhaps prematurely, that no catastrophic hydrologic effects are likely to result from mining and that only local minor changes would be expected.

Herring (1977) pointed out that beneficial use is being made of strip mine groundwater in the humid mid-western climate. Groundwater is

continuously discharged into pit lakes and streams where it may be used for industrial, municipal, or recreational purposes. For example, water from pit lakes may be used in coal preparation plants and for dust control on coal haul roads.

8.2.2 Subsurface Water Quality

The hydrological and geochemical processes controlling groundwater quality were studied in glacial overburden and tertiary strata on undisturbed sites in the North Dakota Fort Union coal formation (Palmer and Cherry 1979). It was concluded that the seven main geochemical processes controlling groundwater chemistry were:

1. production of CO_2 in the rhizosphere;
2. oxidation of pyrite to H_2SO_4;
3. dissolution of Ca and Mg carbonates;
4. precipitation of $CaSO_4$;
5. dissolution of $CaSO_4$;
6. cation exchange reactions involving Ca^{++}, Mg^{++}, and Na^{++}; and
7. $SO_4^{=}$ reduction by bacteria.

The $SO_4^{=}$ content of groundwater is the most critical factor in potability; concentrations above 250 mg/L generally render water unfit for human consumption. The authors reported on the chemical reactions that may explain $SO_4^{=}$ levels in excess of this critical level. With time, however, the sodic clays would be progressively flushed with water rich in dissolved Ca^{++}. The availability of Na would gradually decrease and groundwater quality would slowly improve, provided groundwater flows out of the site. These theories are highly relevant to reclamation in Alberta.

Increased mineralization of groundwater in Montana strip mine spoil was most notable immediately after mining and spoil formation, and declined markedly with time from spoil formation (Van Voast, Hedges and McDermott 1976; Van Voast, Hedges and Pagenkopf 1975; Figure 8.1 and 8.2). Nitrate leaching patterns are anomalous as a large transient nitrate peak concentration is formed immediately after mining commencement (Figure 8.3).

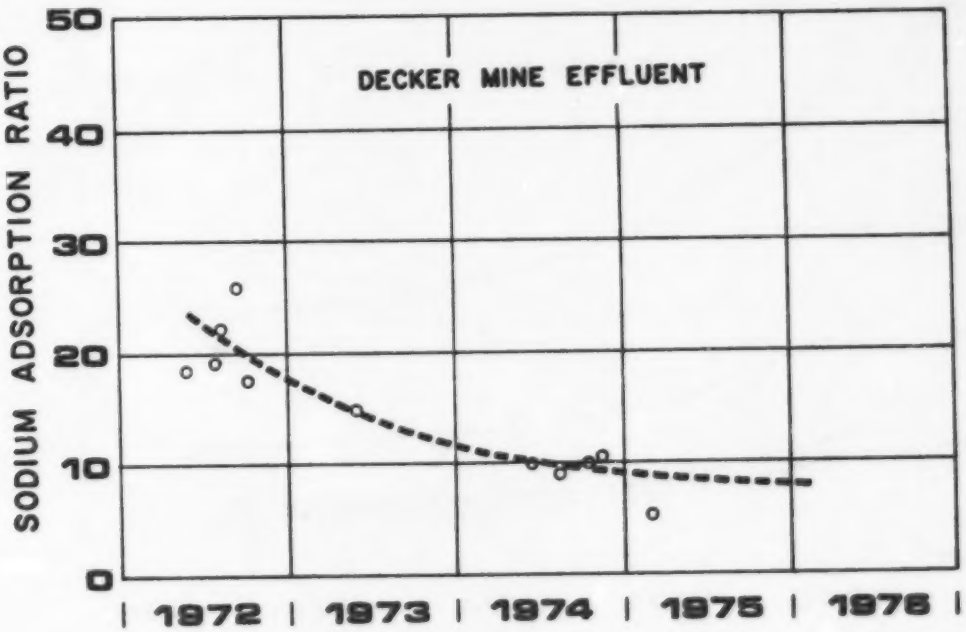

Figure 8.1. Sodium adsorption ratios determined for Decker Mine effluent since mining began.

Source: Van Voast, Hedges and Pagenkopf (1975)

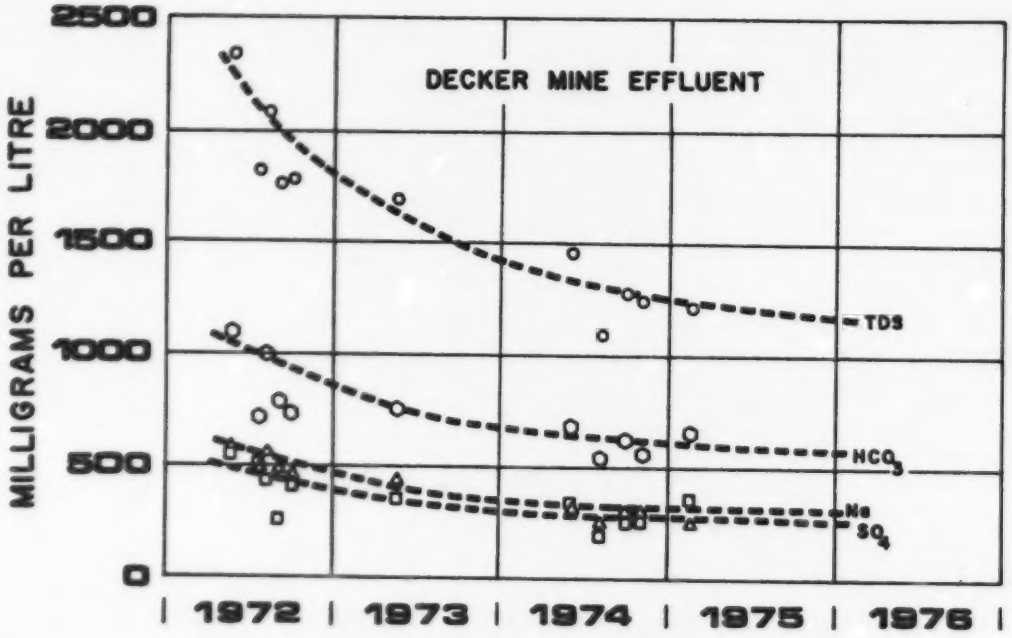

Figure 8.2. Concentrations of total solids and selected constituents in Decker Mine effluent since mining began.

Source: Van Voast, Hedges and Pagenkopf (1975)

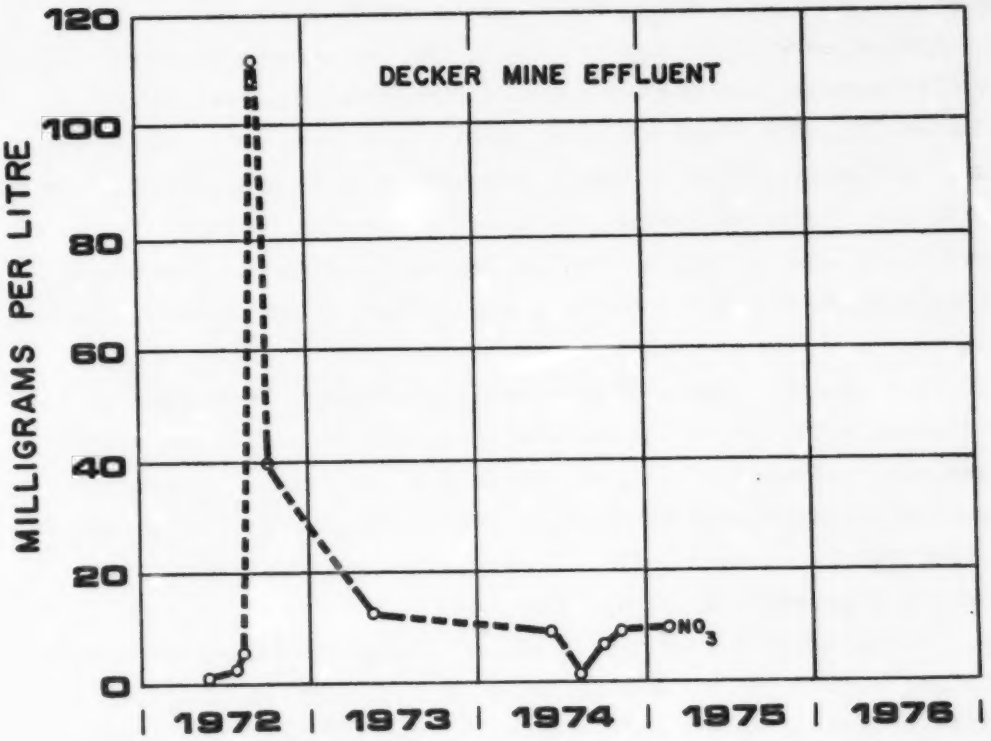

Figure 8.3. Concentration of nitrate in Decker Mine effluent since mining began.

Source: Van Voast, Hedges and Pagenkopf (1975)

This is attributed to very soluble nitrate compounds in residual explosives in the spoil (Van Voast, Hedges and Pagenkopf 1975).

After several decades of mining, the net effect is a small to very small increase in elemental and salt concentration levels in groundwater (Tables 8.5 and 8.6). It should be pointed out, however, that without a historical record of spoil aging, such as is available for the eastern United States and Europe, and considering that the spoil geochemical systems in Montana have not reached equilibrium (Van Voast, Hedges and McDermott 1976), long range predictions of water quality cannot be made.

The mineral content of mine spoil groundwater in Montana is higher than adjacent natural groundwaters but only in some ionic species. For example, in 20 samples of spoil groundwater, SO_4 content exceeded 250 ppm, the recommended drinking water limit. Most samples were high in Ca, Mg, and total dissolved solids. Calcium was the only element that exceeded the recommended drinking water limit.

The geochemistry of mine drainage in Applachia was reviewed by Caruccio and Geidel (1978). The oxidation of iron sulfides initially results in production of H^+, Fe^{++}, and $SO_4^=$. The Fe^{++} ion can be further oxidized to Fe^{+++} with release of considerable H^+ by the catalytic effect of various sulfur oxidizing bacteria that thrive at a pH of about 3. After the acid reaction begins, it becomes self propagating with the acid-producing mechanisms operating synergistically. Pyritic sulfur exists in two forms. One is massive and relatively inert. The other, framboidal pyrite, is highly reactive and the major source of SO_4. Framboidal pyrite is associated with marine-brackish origin coal. This study then, may have some limited relevance to Alberta. Small amounts of widely disseminated pyrite are found in the Jurrasic Alberta coals; however, this is probably of mineral form, although it has not been determined as yet.

In the more moist environment of central Illinois, Pietz, Peterson and Lue-Hing (1974) indicated that the crushing and placement of overburden materials near the water table resulted in a greater surface area of the materials being exposed to weathering and leaching actions. The water enriched with CO_2 dissolves more chemical constituents in mine spoil groundwater than in undisturbed soil groundwater.

Table 8.5. Selected chemical analyses of spoil water and other ground waters near Colstrip, southeastern Montana.

	Spoil Water Typical of Rosebud Mine Area	Natural Ground Waters Typical of Colstrip Area	
		A[a]	B[b]
Ca	421	250	14
Mg	306	281	3.4
Na	119	57	603
K	9.9	7.8	3.6
Fe	0.02	0.04	0.65
Mn	0.70	0.03	0.02
SiO_2	17.3	16.2	7.1
HCO_3	333	530	413
CO_3	0	0	0
OH	0	0	0
Cl	14.3	8.2	7.9
SO_4	2166	1404	978
NO_3	10	0.5	0.1
F	0.0	0.1	0.4
TDS	3398	2555	2032
Sp.C.	3510	2720	2610
SAR	1.1	0.6	37.5
pH	7.7	7.7	8.0

Source: Van Voast, Hedges and Pagenkopf (1975).
Note: Constituents in mg/L
Sp.C. (Specific Conductance) in umhos/cm
[a] Deep aquifer in coal bearing strata.
[b] Shallow aquifer above coal bearing strata.

Table 8.6. Examples of dissolved-organic-carbon and trace-element concentrations found in southeastern-Montana mine areas.

Mine area	Dissolved Organic Carbon (mg/L)	Al mg/L	Sb mg/L	As µg/L	B mg/L	Cd mg/L	Cr mg/L	Cu mg/L	Pb mg/L	Lg mg/L	Hg µg/L	Ni mg/L	Se mg/L	Ag mg/L	Sr mg/L	Sn mg/L	Zn mg/L
Undisturbed aquifers, wells																	
Rosebud	1.9	.05	<.20	<2	.23	<.01	<.01	.01	<.05	.04	<.3	.03	<2.0	<.01	2.05	.25	.03
Rosebud	6.4																
Big Sky	2.8	<.06	<.20	<2	.46	<.01	<.01	.01	.07	.05	.4	.03	<2.0	<.01	12.3	.17	.13
Big Sky	2.0																
Decker (Montana Club)	4.4	.07	<.20	<2	.10	<.01	<.01	.01	<.05	.12	<.3	<.01	<2.0	<.01	.14	.20	.33
Active mine areas, pits																	
Rosebud	3.5	.05	.35	<2	.65	<.01	<.01	.01	.07	.05	<.3	.04	2.8	<.01	8.3	.43	.02
Rosebud	3.6																
Big Sky	3.4	<.05	.3	<2	.43	<.01	<.01	.01	<.05	.03	<.3	.03	2.0	<.01	6.5	.16	.02
Big Sky	2.9																
Decker	8.6	1.35	<.20	<2	.15	<.01	<.01	.01	<.05	.19	<.3	.02	2.6	<.01	.3	.07	.02
Mined areas, ponds and pits																	
Rosebud	6.8	.05	.35	<2	.97	<.01	.01	.01	.12	.07	.4	.06	<2.0	<.01	6.8	.46	.02
Mined areas, wells																	
Rosebud	4.4	.10	.20	<2	.49	<.01	<.01	.01	.07	.02	<.3	.04	<2.0	<.01	3.18	.28	.11
Rosebud	8.2	.08	.30	<2	.83	< .1	<.01	.02	.09	.05	<.3	.06	<2.0	<.01	7.10	.31	.04
Rosebud (McKay)	2.0																
Rosebud (McKay)	7.8	<.05	.60	<2	1.50	.01	.02	.03	.21	.03	<.3	.08	8.0	.01	10.0	.95	.05
Rosebud	42.0	.10	.30	4.6	.34	<.01	<.01	.01	.06	.02	<.3	.04	<2.0	<.01	2.26	.35	.03
Big Sky	30.5	.05	<.20	<2	.55	<.01	<.01	.01	.06	.05	<.3	.04	<2.0	<.01	9.0	.35	.04
Decker	5.8	.10	<.20	<2	.13	<.01	<.01	.01	<.05	.35	<.3	.06	2.0	<.01	3.23	.15	.05
Decker	5.4	.32	<.20	<2	.16	<.01	<.01	.01	<.05	.35	<.3	.05	2.0	<.01	2.4	.09	.01

Source: Adapted from Van Voast, Hedges and McDermott (1976)

Note: Be <5.0 µg/L in all samples limit of detection mean levels of dissolved organic carbon in eight sites (not shown) representing effluent from Decker, and spoil from Rosebud and Big Sky ranged from 5.0 to 142 µg/L.

Although little has been published on the role of pyrite in spoil aging and salt release in Alberta, relevant research has been undertaken by the Alberta Research Council and the Kananaskis Center for Environmental Research of the University of Calgary. The prevailing hypothesis at present is that although pyrite does not appear to be a large consituent of coal spoil in central Alberta (Highvale and Battle River sites for example), it seems to play an important role as a catalyst in the conversion of organic sulfur to inorganic sulfates. These sulfates are a major source of salts released from these spoils (E. Wallick, S. Moran and A. Maslowski, Alberta Research Council, personal communication 1983).

8.3 SUMMARY

Groundwater and surface water quantity and quality are altered by mining. Surface and subsurface utilization of land may conflict, and therefore pre-planning of reclamation is required.

In plains and dry areas, moisture deficits and salinization are problems, while in high rainfall areas, flooding and erosion are of concern.

Flow from mined watersheds may be more variable than from unmined watersheds and tend to larger storm flow and lower base flow (stormflow is controlled by surface runoff; base flow by groundwater discharge). However, stripmining may increase base flow due to increased infiltration and increased storage capacity in saturated soil zones; runoff will then be decreased. Too much infiltration may be a problem, particularly in high rainfall areas. The excess must be removed by improved surface drainage.

Slope percent, texture, bulk density, SAR, and topsoiling influence available soil moisture in mined as well as unmined land; therefore, moisture relationships are usually quite site specific.

Mining can disrupt subsurface flow, recharge, aquifers and thus water supply.

Surface water on plains' strip mines may be chemically unsuitable for irrigation or livestock use. Often there is an increase in release of salts and heavy metals, even in very arid areas.

Changes in water quality lag several months behind mining activity due to the time required for weathering and water percolation. However, some studies have shown that increased mineralization occurs immediately after mining and decreased with time. To date, long range predictions of water quality cannot be made.

There are significant differences between growing and dormant season for many variables. Difficulties in modelling water flow relations to chemical reactions stem from variations in spoil properties, unknown chemical reaction rates, and unknown distribution of acid producing potential between surface and groundwater flow. At present, static models can be produced. Recent studies in the plains area of Alberta are addressing these problems.

Groundwater chemistry is controlled by production of CO_2, oxidation of pyrite, dissolution of Ca, Mg and $CaSO_4$, precipitation of $CaSO_4$, SO_4 reduction by bacteria, and cation exchange reactions.

Sulphate is most important in water potability of plains regions. Natural flushing with Ca rich water will eventually improve quality. In humid areas of highly pyritic spoils, acidity is the major problem. Pyrite reduction and acid reaction are self propogating and acid producing mechanisms act synergistically.

Erosion and sedimentation reduce water quality. Settling ponds should be built off of, not across, natural water ways. Grasses are efficient, economical, environmentally safe filters easily adapted to various site conditions. They require minimum maintainance and work very well where flow is low and sediment concentration is high.

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9. PHYSICAL PROPERTIES OF SPOIL/SOIL

Omodt, Schroer and Patterson (1975) developed a quantitative classification of natural premined agricultural soils which they used to assess the productivity of the existing soils, the suitability of the various horizons, and depth requirements for reconstructing soils. Although they identified soil physical properties as one of the critical productivity-limiting factors in reclaiming North Dakota soils, they also used as their criteria four chemical parameters: (1) organic matter, (2) salinity, (3) free lime, and (4) exchangeable sodium. This was done because physical properties are more difficult to characterize due to problems of reproducibility (e.g., bulk density), expense (e.g., texture measurement techniques), and lack of standardization (e.g., structure). Concomitantly and logically, therefore, there is no generalized well-established body of scientific information such as that existing for chemical or fertility measures (SAR or soil organic matter for example) linking crop yield to such physical properties.

9.1 TEXTURE

Omodt, Schroer and Patterson (1975) pointed out that texture is the most permanent of the commonly measured physical properties of soils. The proportions of the different size fractions comprising the mineral soil materials change very slowly.

To a large extent, texture determines the soil or spoil quality for plant growth. Sandy soils, low in organic matter, have a low cation exchange capacity and therefore are usually low in plant nutrients. Sands do not aggregate, and thus they exhibit weak structures and erode easily. The water holding capacities of sands are low; therefore they tend to be droughty. Medium and fine textured soils possess a higher nutrient holding and supplying capability, water holding capacity, and frequently erosion resistance.

Haynes and Klimstra (1975) stated that spoil banks composed of loams and silty materials are the most productive because they provide the most favourable aggregation, drainage, aeration, available nutrients, and

moisture supply. In contrast, clay soils tend to be less productive due to poor drainage and aeration, excessive compaction, and surface crusting.

Omodt, Schroer and Patterson (1975) also drew attention to the effects of variations with depth in texture and pore size distribution on water retention and movement. Fine textured impervious materials placed under sandy materials may result in perched water tables and soil anaerobosis. Where clay overlies sandy textured material water will not penetrate the sand until the clay is close to saturation since the matric suction in the sand is markedly lower than that in the clay. Considerations such as these are important in planning landscapes of strip mined areas. The placement of materials with highly erodable textures in exposed positions should be avoided.

Exposure of some overburden materials to the atmosphere can cause a shift in particle size distribution in a relatively short time. On spoils in the Somerset Coal Field, Great Britain, Down (1975) reported that particle size distribution changed toward the smaller sizes on spoil surfaces during the first 21 years after mining (Table 9.1). Subsequently, aggregation tended to change the particle size distribution back towards the larger size. At 10 cm depth, however, breakdown of larger particles is minimal, and at 20 cm depth no textural change occurred. The evidence indicates that even with the more easily-weathered and degraded mine spoil of shale origin, textural change occurs only at or very near the spoil-atmosphere interface.

Despite differences in materials mined, spoil banks may have similar physical characteristics. Lanning and Williams (1979) pointed out that large quantities of sand tips come from kaolin extraction as well as micaceous waste deposited in lagoons bounded by sand waste. This sand requires heavy fertilization to revegetate and is apparently similar to spent sands in the Fort McMurray oil sand extraction (Regier 1976).

According to Guerra (1973) the texture of iron ore tailings in the Labrador Peninsula varied from sandy (300 um) to silty (20 um). The mineral extraction process markedly influences the physical characteristics. Texture of Alberta strip mine spoil varies from coarse to fine. For example, Tent Mountain spoilbank contains only 18.5% soil (i.e.,

Table 9.1. Particle size, expressed as % of total sample weight in relation to age and depth of soil sample from the United Kingdom.

Sample age (years)	Depth (cm)	Particle size (μ)									
		Above 9530	9530 to 4000	4000 to 2000	2000 to 1000	1000 to 500	500 to 210	210 to 125	125 to 63	63 to 45	Below 45
0	0	38.6	23.9	13.2	9.2	5.9	4.7	1.9	1.5	0.8	0.3
	10	38.4	17.0	13.4	12.0	9.2	6.5	3.9	1.6	1.3	0.1
	20	42.6	23.3	11.9	8.1	5.7	4.4	1.7	1.2	0.7	0.5
5	0	13.8	17.8	17.9	16.5	12.8	10.1	3.9	3.1	1.8	2.2
	10	26.7	20.3	21.3	14.5	7.3	4.8	2.4	1.6	0.8	0.4
	20	53.0	16.1	12.6	7.9	4.3	3.0	1.4	0.9	0.5	0.2
12	0	5.7	12.8	18.9	20.2	17.7	14.2	4.9	3.2	1.6	0.9
	10	34.1	19.3	16.2	13.8	8.4	5.2	1.7	1.4	0.8	0.2
	20	71.2	8.8	6.5	5.3	3.3	2.1	1.1	1.1	0.5	0.2
21	0	1.4	15.4	23.0	25.4	14.5	9.4	3.9	2.5	3.0	1.2
	10	36.9	21.6	14.3	10.5	6.7	5.1	2.0	1.4	0.9	0.4
	20	32.5	24.5	14.8	10.7	7.0	5.2	2.3	1.5	1.2	0.4
45	0	5.8	15.6	19.8	24.9	16.5	10.1	3.2	1.8	1.0	1.4
	10	26.1	16.8	18.5	18.5	10.2	5.7	1.9	1.2	1.1	0.1
	20	72.5	8.8	6.6	5.7	3.1	1.8	0.6	0.4	0.2	0.2
55	0	2.7	9.1	24.9	28.8	17.1	9.4	3.2	1.9	1.9	0.9
	10	19.2	22.0	19.9	16.9	10.4	6.2	2.1	1.3	0.8	1.1
	20	34.1	24.0	15.7	11.1	6.6	4.4	1.6	1.1	0.5	0.9
98	0	12.3	22.6	22.2	17.7	10.4	7.3	3.1	2.0	1.2	1.4
	10	23.0	20.1	19.8	14.3	8.5	6.5	2.9	2.0	1.2	1.3
	20	31.6	20.5	15.1	12.4	8.0	5.9	2.5	1.9	1.1	1.1
178	0	8.4	12.2	20.2	23.6	19.2	6.0	4.6	2.7	1.8	1.3
	10	24.3	21.7	19.2	15.1	7.3	4.5	3.6	2.2	1.5	0.9
	20	33.4	22.4	16.0	10.4	7.5	5.5	2.1	1.4	1.0	0.1

Source: Dawn (1975)

material < 2 mm diam.; Table 9.2). At Grande Cache, the spoil at No. 9 Mine was sand loam to loam (Macyk 1979), and at Keephills the strip mine overburden was sandy loam, clay loam, and clay (Schumacher 1978).

9.2 STRUCTURE

Omodt, Schroer and Patterson (1975) defined soil structure as specific groupings of silt and clay particles into aggregates, which is reasonably close to the official Canadian terminology. Sometimes structure is erroneously construed to mean particle size distribution (Guerra 1973). Haynes and Klimstra (1975) qualitatively described the effect of soil structure on soil water, heat flux, aeration, and productivity. Proper tillage influences soil structure favourably by enhancing rhizosphere characteristics. Excessive tillage can cause soil structure to deteriorate. Omodt, Schroer and Patterson (1975) described these effects qualitatively, except for organic matter accumulation (Table 9.3), as influenced by climate and soil depth.

Aggregate stability is important since well aggregated soil peds can withstand rain impact and tillage better than loosely aggregated soil structures. Problems with tillage, erosion control, and crop production occur when aggregates break down easily. The organic matter humus fraction strengthens soil structure whereas sodium or free lime in excessive quantities reduce aggregate stability. Omodt, Schroer and Patterson (1975) stated that where free Mg or Ca or unbound carbonates is > 10%, aggregation in fine textured soils is weak. Breakdown under rain impact or tillage reduced infiltration and increased susceptibility to wind and water erosion.

Gee, Bauer and Decker (1978) discussed the physical properties of spoil materials and their measurements. Wet sieving, which measures particle dispersion and aggregation, can be used to assess soil structure. These measurements, together with crust strengths, can reflect the sodium influence on soil structure. Sodium deflocculates soil particles relative to the quantity of Ca + Mg and other divalent cations present.

Table 9.2. Particle size distribution of Coleman Collieries Tent Mountain strip mine spoils in the Crowsnest Pass, Alberta.

	Average Particle Size (mm) by Dry Sieving (% by weight)					
	< 2	2 to 4	4 to 6	6 to 12	12 to 19	19
Mean of 12 Samples	18.5	16.2	10.0	16.3	11.2	27.8
Standard Deviation	5.8	4.1	2.2	3.0	3.8	9.9

Source: McCoy (1975).

Table 9.3. Mean organic matter of two soil profiles, by depths and rate of accumulation based upon a 350-year radiocarbon date, in northeast and southwest North Dakota.

Depth cm	Total Organic Matter t/ha		Accumulation/year kg/ha	
	NE	SW	NE	SW
0 to 31	161	101	460	292
0 to 61	191	168	538	476
0 to 152	235	206	673	583

Source: Adapted from Omodt, Schroer and Patterson (1975).

[a] Precipitation in SW is 8 to 13 cm lower than in NE.

9.3 BULK DENSITY

Bulk density of a soil or spoil refers to the mass unit volume of the material. Commonly, natural soils have bulk densities in the order of 1.5 g/cm^3. The specific gravity of the individual mineral particles of soil is commonly held to be 2.65 g/cm^3. Thus, somewhat less than half of the total volume of soil is mineral solids. The remaining soil volume is occupied by soil solution and soil gases.

Struthers (1965) suggested chemical weathering can be an important agent of long term mine spoil amelioration. Air and water entry across the soil-atmosphere interface requires a porous surface and in turn promotes weathering. Aeration permits intense soil biological activity including microbial and root metabolism. Thus, bulk density can influence these processes in soils and spoils. Furthermore, as bulk density increases, soil infiltration and permeability decreases. In general, moderately low bulk densities are desirable. Some authors feel that cultivation promotes low soil bulk density, aggregation, and desirable soil tilth and structure. However, full discussion of the effects and controversy relating to cultivation on soil structure is beyond the scope of this review.

Omodt, Schroer and Patterson (1975) recognized the unique problems in spoil reclamation caused by compaction from the heavy equipment used for levelling spoil and spreading amendments. They recommended chiselling of reworked spoil after land forming and before top-dressing to facilitate infiltration and percolation. They also discussed the bulk density related problem of large spoil voids caused by large overburden blocks. After grading or levelling, surface channels and hollows may develop from infilling of these voids over time. This problem can be minimized by spreading overburden over a wider area during stripping and by avoiding grading and levelling it when the spoil is frozen.

Some authors reported increased spoil bulk densities, suggesting limited spoil water permeability and storage capacity, while others reported decreased bulk density in spoil after mining. At Keephills, Alberta, for example, the Quarternary and Cretaceous origin overburden has bulk densities of 1.7 to 1.9 g/m^3 (Schumacher 1978). This is markedly

higher than bulk density in agricultural soils suggesting low spoil permeability and limited aquifer storage capability. It must be realized, however, that spoil bulk density is usually lower than the original overburden. For example, Gee, Bauer and Decker (1978) reported that the increase in volume (and the inevitable decrease in bulk density) due to disturbance for overburden materials in North Dakota was 20 to 25%.

In the Crowsnest Pass and Elk Valley areas of Alberta and British Columbia, Harrison (1974) reported that spoil bulk density is influenced by both material composition and compaction history. Weathered bedrock and spoil ranged from 1.377 to 1.620 g/cm^3 at the dump platform. At the free face, Carbonaceous shales and sandstone ranged from 0.972 to 1.134 g/cm^3 and at the dump platform 1.134 to 1.458 g/cm^3. Bituminous coal in situ was 0.972 kg/m^3 whereas wheel-compacted coarse refuse was 1.215 to 1.296 g/cm^3.

Differences in mine spoil bulk density related to vegetative treatment were discussed by Macyk (1977a). At Grande Cache, Alberta, spoil bulk densities varied from 1.07 to 1.81 gm/cm^3 on disturbed sites. The lower values were on plots established for five years with minimum compaction and relatively high organic matter contents. Areas not vegetated since the application of a topsoil dressing had higher bulk densities. Similarly, Montreal Engineering Company Ltd. (1978) discussed the effects of green manuring on soil organic matter accumulation and the lowering of bulk density and increased aeration.

Curtis (1973) reported on moisture and density relationships on graded strip mined spoils in Kentucky. On an undulating spoil surface two plots were scarified 20 to 25 cm in depth, using a road grader with teeth 45 cm apart, and two plots were not scarified. Density measurements the following year suggested the effect of scarification on bulk density was quickly masked by settling during rainstorms.

The unscarified areas, however, exhibited surface bulk density reduction over the nine months of the study. A significant difference between ridge and valley bulk densities existed down to 2.7 m soil depth but not at greater depths. Subsurface layers in the valleys were about 0.324 g/cm^3 less dense than ridges whereas the surface layers had similar

densities. Grading equipment affected bulk density to a depth of 30 cm only.

9.4 MOISTURE RELATIONS

The soil moisture content, infiltration rate, soil water flux, and vertical and horizontal distribution gradients are influenced by soil texture, structure, organic matter content, and soil chemistry and biology. Mine spoil moisture characteristics depend on overburden characteristics and its handling during mining. Modification of spoil banks by grading and amendment application, and by natural weathering changes the spoil moisture relations.

In arid regions of the North American Great Plains, moisture usually limits crop growth in disturbed and undisturbed soils. Even in humid areas, moisture stress may be a major factor in the revegetation of mine wastes. In Pennsylvania, Thompson and Hutnik (1972) reported that the moisture content 2.5 cm below the surface of steep slopes of mine and coal processing wastes was consistently below the permanent wilting point. This surface dry layer impeded vegetation establishment though the moisture content was sufficient at a depth of 23 cm.

In Alberta, the water holding capacities of some coal mine spoils are relatively large. For example, Schumacher (1978) found that the Quarternary and Cretaceous materials overlying coal at Keephills, Alberta, had available water-holding capacities (field capacity at 0.1 atm minus wilting point at 15 atm) from 0.1 to 0.2 cm/cm^3.

The type of vegetation re-established on spoils can affect soil moisture distribution with depth. According to Curtis (1973), in western Kentucky grass and legumes rapidly deplete soil moisture in the surface 30 cm whereas trees may have little effect on spoil moisture content for several years. However, during the first year after establishment when rainfall was 38 cm, vegetation density had no apparent effect on moisture content. Differences in moisture content were due largely to differences in infiltration and percolation rates. Low infiltration rates were due to puddling, crusting, and compaction on graded sites. Ungraded sites had higher infiltration rates.

On levelled North Dakota mine spoils. Bauer et al. (1978) studied the relationships between fertilization, crop water use efficiency, and yield performance for Triticum aestivum, Zea mais, and a grass/legume mixture. Generally, at least 15 cm of topsoil over spoil were required for adequate soil fertility. Within these acceptable treatments, soil water withdrawal under Triticum and Zea did not extend below 1.2 m and was often less than 60 cm. Most moisture was removed from the surface 30 cm. Grass/legume crops withdrew water to at least the 1.5 m depth with 70% of the total withdrawal coming from the surface 60 cm.

Water use efficiency varied with years, crop and topsoil thickness. For Triticum grain, it ranged from 7 to 53 kg/ha/cm of water evapotranspirated, Zea silage (dry matter) from 95 to 303, and grass legume from 104 to 164. Crop limiting yield responses to moisture stress were marked and more significant than nutrient deficiency.

The high degree of variability in moisture measurements obscured or limited the interpretation of trends to some degree. For example, Triticum at the Consolidation site apparently withdrew more water from low N fertilized plots than from heavy N fertilized plots (Table 9.4). These results are contrary to what would logically be expected, and may be due to marked spatial variability in bulk density and thus water holding capacity of disturbed soils as compared to undisturbed soils.

Conversely, Zea and Triticum at the Knife River site showed the expected trends (i.e., extraction of more moisture as shown by increasing moisture difference near the soil surface and over the length of the growing season; Tables 9.5 and 9.6).

Using the assumption then that soil moisture change at depth was due primarily to plant transpiration (which they did not test), the authors extrapolated the depth of root extension from the depth of water depletion. From the lack of moisture content change at 1 m soil depth, as shown in Table 9.7, they concluded root extension was limited to 1 m.

Water use efficiency (yield/unit area/unit amount of water lost) was calculated for the three crops grown at the three research sites (Table

Table 9.4. Total soil water content (cm) and the difference in the amount at seeding and harvest under wheat grown at two soil fertility levels in 1976, at Consolidation Coal Company, Montana.

Nitrogen(N) kg/ha	Season	Soil Depth (m)				
		0 to 0.3	0.3 to 0.6	0.6 to 0.9	0.9 to 1.2	1.2 to 1.5
0	Spring[a]	10.08	10.67	9.58	7.57	7.87
	Fall[b]	5.08	10.34	10.74	8.97	9.65
	Difference	5.00	0.33	-1.16	-1.40	-1.78
45	Spring[a]	10.01	10.19	9.20	8.56	6.71
	Fall[b]	5.26	9.35	10.62	10.26	7.93
	Difference	4.75	0.84	-1.42	-1.70	-1.22

Source: Adapted from Bauer et al. (1978).
Note: Average of four holes/treatment. The access tubes were placed in plots receiving 45 kg/ha broadcast P and 12 kg/ha banded.
[a] 27 April 1976 = Spring
[b] 05 August 1976 = Fall

Table 9.5. Total water content (cm) and the difference in the amount from seeding and harvest under wheat grown on four topsoil thicknesses in 1976, Knife River Coal Company, Montana.

Topsoil thickness cm	Season	Soil Depth (m)				
		0 to 0.3	0.3 to 0.6	0.6 to 0.9	0.9 to 1.2	1.2 to 1.5
5	Spring[a]	12.34	13.00	11.68	11.38	11.13
	Fall[b]	7.65	11.58	11.02	11.48	11.13
	Difference	4.70	1.42	0.66	-0.10	0.00
15	Spring[a]	11.71	11.13	11.91	11.79	10.85
	Fall[c]	6.66	9.25	11.33	11.20	10.41
	Difference	5.05	1.88	0.58	0.53	0.43
31	Spring[a]	10.31	9.80	10.62	11.74	10.74
	Fall[b]	4.72	7.62	10.06	11.05	10.41
	Difference	5.59	2.18	0.56	0.69	0.33
61	Spring[a]	8.51	10.03	10.80	10.80	10.67
	Fall[b]	4.27	6.91	10.29	10.49	10.49
	Difference	4.24	3.12	0.51	0.31	0.18

Source: Adapted from Bauer et al. (1978).
Note: Average of four holes per treatment. The access tub were placed in plots receiving 101 kg/ha P broadcast at the soil:spoil interface and 34 kg/ha banded.
[a] 29 April 1976
[b] 03 August 1976
[c] 01 August 1976

Table 9.6. Total soil water content (cm) and the difference in the amount at planting and harvest for corn grown at two fertility levels in 1976, Consolidation Coal Company, Montana.

Nitrogen (N) kg/ha	Season	Soil Depth (cm)				
		0 to 0.3	0.3 to 0.6	0.6 to 0.9	0.9 to 1.2	1.2 to 1.5
0	Spring[a]	8.92	10.47	10.08	8.99	8.76
	Fall[b]	4.47	8.64	10.31	9.27	8.97
	Difference	3.94	1.83	-0.23	-0.28	-0.21
45	Spring[a]	9.17	10.01	11.15	10.36	9.80
	Fall[b]	4.67	8.71	11.23	10.57	9.96
	Difference	4.50	1.30	-0.08	-0.21	-0.16

Source: Adapted from Bauer et al. (1978).
Note: Average of four holes per treatment. The access tubes were placed in plots receiving 45 kg/ha P broadcast and 18 kg/ha P banded.
[a] 20 May 1976 = Spring
[b] 01 September 1976 = Fall

Table 9.7. Total soil water content (cm) and the difference in the amount from planting and harvest under corn grown on four topsoil thicknesses in 1976, Knife River Coal Company, Montana.

Topsoil thickness cm	Season	Soil Depth (m)				
		0 to 0.3	0.3 to 0.6	0.6 to 0.9	0.9 to 1.2	1.2 to 1.5
5						
	Spring[a]	12.32	12.95	12.47	11.35	11.18
	Fall[b]	10.82	12.24	12.12	11.02	10.54
	Difference	1.50	0.71	0.36	0.33	0.64
15	Spring	10.82	12.35	12.45	12.04	11.10
	Fall	8.56	11.76	12.01	11.84	11.10
	Difference	2.26	0.58	0.43	0.20	0.0
31	Spring	9.55	12.42	12.85	12.65	12.19
	Fall	6.96	11.76	12.50	12.29	11.53
	Difference	2.59	0.66	0.36	0.36	0.66
61	Spring	6.96	9.45	12.09	11.79	10.21
	Fall	3.43	7.47	11.89	11.48	10.13
	Difference	3.53	1.98	0.20	0.31	0.08

Source: Adapted from Bauer et al. (1978).

Note: Average of four holes per treatment. The access tubes were place in plots receiving 101 kg/ha fertilizer P at the soil:spoil interface and 34 kg/ha banded.

[a] 21 May 1976 = Spring

[b] 03 September 1976 = Fall

9.8). Despite the variability, it is clear increasing soil thickness markedly increased soil water consumption, water use efficiency, and crop yield. Conversely, N fertilization had little effect on the same parameters. This suggests that soil water availability rather than fertility or nutrient levels limited yields in these spoils.

Moisture content may also be important in the handling and engineering stability of mine spoils. Guerra (1973) reported that the uniformly sandy or very fine iron ore tailings in Labrador are susceptible to liquification and sliding, having excessive internal pore water pressures due to heavy rains. Similarly, in eastern Kentucky conditions favouring spoil bank slides include overloading the bank and excess internal pore water pressure (Weigle 1965). Water entering voids between soil particles displaces air, lowers particle surface tension, and the apparent cohesion between soil particles. Infiltrating water raises the water table, increasing pore water pressure and lowering the soil shear resistance.

Macyk (1977b) suggested that soil should not be spread at too high a moisture content (although he did not report specific values) with excessive travelling of heavy equipment. The measured infiltration rates on the mine spoils at Grande Cache, Alberta, are considerably less than in local undisturbed forest soils (Figure 9.1).

If water is available, irrigation may be used in moisture deficit areas to maintain soil moisture at optimum levels for plant growth. De Remer and Bach (1977) stated that irrigation of disturbed lands in the southwestern U.S. is usually necessary where rainfall is <30 cm annually, or is poorly distributed during the year. Moisture deficits and the need for supplemental irrigation also occur where steep slopes result in excessive runoff or where percolation rates are high.

The authors discussed the problems and advantages of sprinkler irrigation. Application rates on spoils often exceed infiltration rates, causing erosion, especially on slopes. Drip or trickle irrigation systems avoid these problems and provide a more efficient use of water; however, they are too costly to apply to extensive areas.

Table 9.8. Water use efficiency (WUE) of wheat grain, corn silage, and grass-legume forage as affected by fertilizer nitrogen or topsoil thickness in 1976 at three North Dakota research sites.

Site	Crop	Fertilizer Treatment	Growing[d] season rainfall cm	Soil[e] water removed cm	Dry matter yield kg/ha	WUE kg/ha/cm
Consolidation	Wheat grain	0 N[a]	21.26	5.33	1096	41
		67 N[b]		5.59	1197	45
	Corn silage	0 N	22.30	5.77	2140	76
		45 N		5.79	2037	72
Knife River	Wheat grain	5[c]	17.32	6.78	753	31
		15		8.48	922	36
		31		9.35	948	36
		61		8.36	1029	40
	Corn silage	5	16.74	3.53	1126	56
		15		3.48	1549	77
		31		4.62	1915	90
		61		6.10	2791	122
Baukol-Noonan	Grass-legume	67 N	23.67	12.24	2602	72

Source: Adapted from Bauer et al. (1978).

[a] Soil water was measured in plots receiving 0 and 45 kg/ha N.

[b] Soil water was measured in plots receiving 0 and 67 kg/ha N.

[c] Soil water was measured in plots with 5, 15, 31, 61 cm topsoil.

[d] Seeding to harvest, or in the case of grass-legume at Baukol-Noonan, interval between access tube readings in the spring and at harvest.

[e] Difference in soil water content to 1.5 m from seeding to harvest.

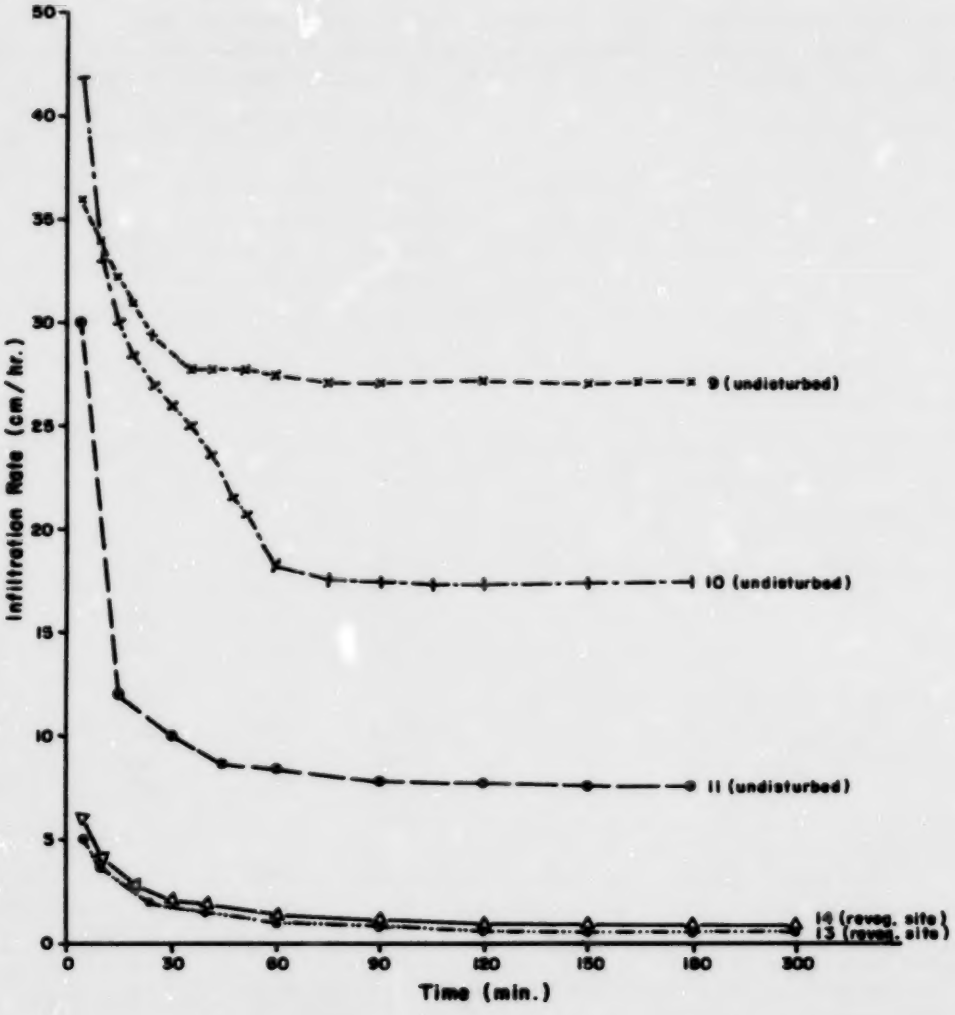

Figure 9.1. Infiltration rates at undisturbed and revegetated sites at No. 9 Mine, Grande Cache, Alberta.

Source: Macyk (1977b).

9.4.1 Infiltration

The rate at which water can enter through the surface of the soil or spoil is important. If rainfall (or irrigation) exceeds the infiltration rate, free water will accumulate on the surface. Where slopes are steep and bare, as usually occurs on mine spoil piles, erosion quickly becomes severe, increasing the difficulty in establishing vegetation. De Remer and Bach (1977) referred to the potential erosion problem where the application rate of irrigation sprinklers exceeds the infiltration rate of the tailings spoil. Struthers (1965) pointed out that chemical changes associated with weathering can improve mine spoil fertility and quality. Since air and water are the primary requirements for weathering, a loose porous surface facilitates air and water entry, accelerating weathering. Concomitantly, however, excess water dilutes and may leach large quantities of salt which in turn could impede plant growth.

Gee, Bauer and Decker (1978) related low infiltration rates to excess sodium (i.e., where SAR > 12). They point out that this has led to topsoiling recommendations. Although sodicity is a prime cause of low infiltration rates on Alberta spoils, there can be other causes. Miyamoto, Bristol and Gould (1977) concluded that low infiltration rates in a New Mexico spoil may have been caused by poor spoil wetability. They found that shiny coal fragments in spoils were water repellant. Whether this repellancy would persist as coal fragments weathered is unknown.

At Grande Cache, Alberta, Macyk (1977a) found spoil infiltration rates were lower on disturbed sites than on undisturbed sites. The highest rate on disturbed sites occurred where vegetation was established and bulk density was relatively low.

On sodic spoils at Decker, Montana, Farmer and Richardson (1976) recommended regrading spoil to final configuration as soon as possible to facilitate infiltration, minimize erosion and promote revegetation. For example, using the Universal Soil Loss Equation suggests that reducing slope from 100% to 20% and height from 36 to 18 m would reduce erosion by 800%. Comparing the effects of the types of overburden, their erosion potential, and topographic factor (a function of slope degree and length)

on erosion, indicated topography was by far the most significant factor (Table 9.9).

Table 9.9 also shows how significant such erosion losses can be while Table 9.10 illustrates how infiltration decreases over time as spoil material ages in stockpiles, thus emphasizing the recommendation to reclaim or regrade spoil as soon as possible. It should be noted that the infiltration rates are similar to those reported by Harrison (1974) in Alberta and British Columbia (Table 9.11).

Curtis (1973) found the infiltration rate on graded coal mine spoils was lower than on ungraded spoils due to puddling, crusting, and compaction.

On a North Dakota mine spoil where the SAR 30, Gilley et al. (1976) found that rototilling altered water infiltration and percolation only on sandy clay to a depth of 15 cm and not on clay loam or silty clay loam. Discing had no discernible effect on spoil water infiltration. Not all coal spoil has shown low infiltration rates or rates lower than local undisturbed soils. Infiltration rates on tailings pond coal spoils in Crowsnest Pass, Alberta, were equal to that of grasslands over glacial materials levels and exceeded precipitation for most summer storms (Harrison 1974, Table 9.11). Little has been reported on the effect of disturbance on other soil and spoil materials, however in the same study (Harrison 1974) compacted pit roadways and finer grained spoil from weathered surface rock had markedly lower infiltration rates, resulting in significant runoff and gullying.

9.4.2 Temperature

Studies by Schramm (1966) of plant colonization on anthracite wastes in Pennsylvania have provided significant information on temperature gradients in spoil and their effects on emerging vegetation. The two substrates studied were refuse (black, mostly shaly, rock coming mainly from the breakers where raw coal is refined) and sludge (the fine coal and mineral particles washed from processed anthracite before marketing).

He found steep decreasing temperature gradients with depth in dry insulated sludge or refuse. For example, surface temperatures in a fine,

Table 9.9. Computed average annual soil loss from coal mine overburden piles at the Decker Coal Mine, Decker, Montana. Two LS values are shown for each overburden type. The low value is based on a vertical overburden pile height of 60 feet with 60 percent slope steepness. The high value is for a vertical pile height of 120 feet, 100 percent slope steepness.

Overburden:	Rainfall factor (R)	Soil erodibility factor (K)	Topographic factor (LS)	Computed annual soil-loss (RKLS) t/ha
1	26	0.31	53	957
	26	0.31	24	433
2	26	0.50	53	1 545
	26	0.50	24	699
3	26	0.34	53	1 050
	26	0.34	24	475
4	26	0.41	53	1 267
	26	0.41	24	574
5	26	0.25	53	772
	26	0.25	24	350
6	26	0.23	53	711
	26	0.23	24	323
7	26	0.38	53	1 174
	26	0.38	24	531

Source: Adapted from Farmer and Richardson (1976:128)

Table 9.10. Average infiltration rate, rate rank, and time between disturbance of overburden material and infiltration tests, Decker Coal Mine, Decker, Montana.

Sample number	Average infiltration rate (cm/h)	Infiltration rate rank	Time since last overburden disturbance (months)
5	3.61	1	1
3	3.12	2	1
6	1.88	3	6
4	.89	4	8 (est.)
7	.86	5	6
1	.53	6	12
2	.30	7	24

Source: Gilley et al. (1976).

Table 9.11. Infiltration rate on waste rock dumps at coal mines in the Crowsnest Pass - Elk Valley areas of Alberta and British Columbia.

Location	No. of Readings	Infiltration (cm/h)
Tailings sands	12	5.84
Pit roadways	4	1.60
Coarse spoil	8	4.75
Till, weathered rock	2	0.66

Source: Harrison (1974).

dry refuse ranged from 63 to 67°C while readings at a depth of 25 mm were 43.5 to 49.5°C. In moist spoils, however, these depth gradients were not present; rather, gradients developed as the spoil dried. In coarse refuse, where capillary rise of water is negligible, surface drying occurred quickly, resulting in a steep temperature increase (Table 9.12). On the other hand, due to greater capillary uptake, surface dessication proceeds much slower in fine-textured sludge as does the formation of temperature gradients. Schramm noted the same characteristics have been found in mineral soils.

Thompson and Hutnik (1972) in Pennsylvania also reported high surface temperatures on refuse banks caused by dry surface layers and exposure to solar radiation. At five sites, representing different aspects, 50°C (the generally accepted critical temperature for many plants (Bidwell 1974:568)) was frequently exceeded. A high of 71°C was recorded and temperatures of 60°C were common. Dangerously high temperatures persisted for at least three hours per day. Temperatures of 49°C were common at 1 cm soil depth with mean temperature gradients between the surface and 1 cm soil depth of about 1.6°C. In the laboratory, Harrison (1974) found that fine coal spoil with 30% ash content had a thermal conductivity equivalent to loose snow and specific heat close to that of iron.

Schramm (1966) found great variations in surface temperature of sludges in situ and attributed these to differences in distance from the surface to the sensible moisture contour. To test this hypothesis, an experiment was run to examine the effects of 1.3, 2.5, 3.8, 5.1, and 6.4 cm of air-dry sifted sludge (20 to 40 mesh) in a layer over a wet, but drained, sludge base. A surface layer of a similarly sifted white quartz sand 1.3 and 3.8 cm deep was also tested. A second experiment was set up without the quartz covers, while a third experiment included a plot which had no dry covering layer.

From these experiments Schramm found a positive correlation between temperature of the dry surface and its distance from the sensible moisture level (Table 9.13). Temperature in the dry spoil material was substantially higher than in the moist spoil (third experiment, Table

Table 9.12. Daytime course of surface temperature (°C) of undisturbed insolated refuse in Pennsylvania following heavy rains preceding day.

Mercury thermometer number and placement	Temperature, Eastern Standard Time[e]										
	7:30[a]	7:45[a]	8:40[b]	9:15[a]	10:00[a]	11:00[c]	11:50[a]	12:50[a]	1:30[a]	3:00[d]	4:10[c]
No. 1 Horizontally in surface; bulb barely covered	28	30	36	39	43	41	42.5	45	45	46.5	41
No. 2 Horizontally in surface; bulb barely covered	29	31	37	40	45	43	44	47	46	47	41.5
No. 3 In air and shaded *ca.* 23 cm above surface	24	24.5	27	28	30.5	30.5	31	32	32	34	32

Source: Adapted from Schramm (1966:31)

[a] Sunny interval.

[b] Interval alternatingly sunny and cloudy.

[c] Interval mostly cloudy.

[d] Interval mostly sunny.

[e] In the earlier morning readings the surface was very moist, with only coarser top fragments dry; thereafter the surface increasingly lost all appearance of being moist. How deep the dry layer had become when readings ended was not ascertained.

Table 9.13. Effect of proximity of sensible moisture contour to the surface (i.e., depth of dry layer) on temperature of dry sludge surfaces in Pennsylvania.

Depth in cm of layer of dry sifted sludge or white quartz sand resting on unsifted wet sludge	Surface Temperature (°C), E.S.T.							
	Experiment 1[a]				Experiment 2[b]			
	11:30	11:50	12:10	12:30[a]	12:10	12:30	1:35	Average
1.3 of sludge	51.5	52.0	52.0	47.0	49.5	51.0	48.0	49.5
2.5 of sludge	55.5	56.0	55.0	50.0	55.0	56.5	53.0	54.9
3.8 of sludge	57.5	58.5	58.0	52.5	55.0	56.0	53.5	54.9
5.1 of sludge	60.0	60.5	59.0	53.5	56.5	58.5	55.5	56.7
6.4 of sludge	60.5	62.5	61.5	56.0	56.5	58.0	55.5	56.5
1.3 of white quartz sand	39.0	41.5	42.0	42.0	ND[c]	ND	ND	ND
3.8 of white quartz sand	41.0	44.0	44.5	44.5	ND	ND	ND	ND

Source: Adapted from Schramm (1966:32-33)

[a] Until shortly after the 12:10 reading it was sunny though somewhat hazy; thereafter considerable cloudiness prevailed, August 7.

[b] Sky clear throughout experiment, August 26.

[c] ND = no data.

Table 9.14. Effect of proximity of sensible moisture contour to the surface (i.e., depth of dry layer) on temperature of sludge surfaces, Pennsylvania, September 3.

Depth in cm of layer of dry sifted sludge resting on unsifted wet sludge	Surface Temperature (C.), Eastern Standard Time							
	11:30	11:40	11:45	12:10[a]	12:30[b]	12:40[b]	1:30[b]	Average
0	34.5	35.5	35.5	31.5	34.5	37.5	38	35.3
2.5	49.5	52	53	46.5	53.5	56	55.5	52.1
3.8	48.5	53	53.5	48.5	55	58	58	53.2
5.1	49	53.5	53.5	50	55	58	58.5	53.6
6.4	50.5	54.5	55	51.5	55.5	60	59.5	54.9

Source: Adapted from Schramm (1966:33)

[a] Interval mostly cloudy.

[b] Interval clear.

9.14). The greatest increase in temperature occurred in the first 1.3 cm of spoil. Though unable to test with greater precision, Schramm felt that this rise in temperature was concentrated primarily in the first few millimetres of spoil where radiant energy is absorbed and converted to heat.

The effect of surface colour on temperature is also demonstrated in Table 9.13. With a 1.3 cm layer of white quartz sand, surface temperatures were 10 to 12°C lower than with a similar layer of black sludge. With a 3.8 cm layer the difference was 13 to 16°C. In addition, the increase in temperatures with increasing cover depth were less for the quartz treatment (2.1°C) than for the anthracite treatment (5.9°C).

Schramm explained that the rise in surface temperature was due to the low conductivities of the interstitial air in the dry layer. This low conductivity limited heat conduction down the profile. Thus any interference with the transfer of heat down the profile would increase surface temperatures in dry spoils.

To test this, he placed an herbarium blotter over moistened, unsifted sludge, then covered the blotter with 1.3 cm of dry, sifted sludge (20 to 40 mesh). A control plot was set up in a similar manner without the blotter. The surface temperature in the plot with the blotter was, on average, 7.4°C higher than in the control plot. These results indicate the importance of considering all attributes of a soil amendment and incorporation procedure when planning a reclamation strategy. As an example, Schramm discussed a trial in which peat was placed as a subsurface layer to improve moisture conditions. Though the peat did indeed hold moisture, it also acted as an insulator and surface temperatures were several degrees above those in adjoining unamended spoil.

As in dry soil, grain size in spoil will substantially and directly affect surface temperature. Schramm found that an increase in particle size from 80 mesh to 10 mesh in the top 1.3 cm of spoil caused an increase in temperature from 37 to 41°C. This effect is due to the increased volume of air in coarser spoils and the decreased particle-to-particle contact. These two factors also lead to an increase in drainage and deeper dry layers, which also causes warmer temperatures.

The effects of angle of incidence of sunlight and of spoil slope were demonstrated by Schramm in an experiment with sludge placed at angles of 10°, 20°, 30°, and 40° on a south exposure, 10° and 20° on a north exposure, and horizontal. At meridian time for the site, then, the equivalent angles of incidence ranged from 40° to 90° in increments of 10°. The data in Table 9.15 show that there was little change in temperature when the angle of incidence was between 70 and 90°; however, surface temperature dropped rapidly with decreasing angles. At an angle of 40° surface temperature was 14.5°C lower than on plots receiving sunlight at 70 to 90°.

The effect of slope may also be seen in Table 9.15. On the moderate 20° northern slope the temperature was 15°C cooler than on the similarly inclined southern slope. In a second experiment on a 22° south slope and 26° north slope, Schramm found an 11 to 12°C temperature difference had developed by noon. In the Crowsnest Pass, Alberta area, Harrison (1974) recorded temperatures as high as 73°C on south facing 26° spoil slopes. There can be a 10°C difference in maximum temperature between south and north facing slopes. These temperature extremes may limit vegetation on the south-facing slopes.

Schramm (1966) has also discussed the effects of elevated surface temperatures on seedling germination and growth. Heat injury resulting in stunted growth or death was demonstrated in several species planted or sown in the wastes. Examples given by Schramm include: Pinus strobus, P. sylvestris, Salix humilus, Populus tremuloides, P. grandidentata, Ginkgo biloba, Robinia hispida, Comptonia peregrina, Lysimachia terrestris, Pyrus melanocarpa, Parthenocissus quinquefolia, Potentilla canadensis, and Scirpus americanus.

Injury is commonly restricted to the area of the seedling which is in contact with the shallow surface layer in which radiation is converted to heat and where, as mentioned previously, the highest temperatures occur. In plants with an upright habit, injury is commonly in the form of a girdled stem. In a study of 65 Salix humilus stems, Schramm noted that most of the stem burns were concentrated on the southerly exposed portion of the plant stems. In prostrate plants with runners such

Table 9.15. Effect of angle of insolation on temperature of sludge surfaces, in Pennsylvania. (Grain size of dry surface layer only controlled).

Angle of incidence of direct sunlight on prepared surfaces at meridian time (12:11 E.S.T.) at Pottsville, Pennsylvania, August 26.	Temperatures (°C), Eastern Standard Time[a]													
	11:20	11:30	11:35	11:45	11:55	12:00	12:05	12:15[b]	12:25	12:35	1:30	2:05	3:15	3:50
90° Surface No.1: sloping due south 30°C	52	56	58.5	55	57.5	58	58	60	60	56.6	55	56.5	44	40
80° Average of the temperatures of Surface No.2a (sloping south 20°) and Surface No.2b (sloping south 40°)	52.0	55.5	58.0	55.5	58.2	58.7	59.2	60.7	60.7	57.7	56.0	56.5	44.5	41.0
70° Surface No.3; sloping due south 10°C	51	55	57	55	57.5	58	58.5	59	60	57	55.5	56.5	44.5	41.5
60° Surface No.4; horizontal	49	52.5	54.5	53	55.5	56	56.5	56	57.5	55	54	55	44	41.5
50° Surface No.5; sloping due north 10°C	44	47	48	47	49	49.5	50	50	51	49.5	47.5	50	41.5	39
40° Surface No.6; sloping due north 30°C	41	43	44	43.5	44.5	45	45	45.5	46	45.5	45.5	45.5	40	37.5

Source: Schramm (1966:37)

[a] Day cool and clear, with very gentle variable winds. Air temperature 0.3 m above sludge surface (thermometer shaded), 39°C at 11:35.

[b] The reading nearest meridian time.

[c] The inclinations to the north were used to achieve angles of incidence less than 60°. To accomplish this by south-facing slopes was impractical, the dry sludge beginning to roll at angles greater than 40° from the horizontal.

as Parthenocissus quinquefolia, Potentilla canadensis, Rubus spp. or Polygonum spp. Injury occurs where the stems make contact with the surface. Schramm cited several examples of prostrate shrubs growing on cool northern slopes where the apical portions of the plant are killed when the plant tries to extend over the top of the slope onto the hotter southern exposure. Lethal temperatures rarely exist more than 1.3 cm below the spoil surface, and thus few roots are heat killed. Only when the surface is eroded (e.g., by wind, water, vehicle traffic, etc.) are the roots exposed to potentially lethal temperatures.

When plants do become established, however, the shade provided by stems and leaves creates a microclimate more conducive to seedling germination and growth. For example, an area populated by tiny Populus seedlings was found to have a surface temperature 13°C cooler than that of an adjacent bare spoil surface.

To test the effects of shade on germination, Schramm designed small plots which provided shade on 12 to 89% of the spoil surface. In the plots receiving the most shade (89, 75, and 59%) the combined density of volunteer Populus tremuloides and P. grandidentata was high, with 108, 51, and 42 seedlings, respectively. In the plots receiving less shade germination was significantly lower. Temperatures in the plots ranged from 40.5° (23% shade) to 27.5°C (89% shade).

Schramm also studied the effects of shade on germination of Pinus strobus. Seeds were sown 07 May in plots receiving full insolation, shade or insolation to 17 June and shade thereafter. By 17 July, less than 1% of the seedlings had germinated in the plots receiving full insolation. In the partially shaded and shaded plots germination was much higher, 50% and 80%, respectively. By 08 November, germination rates were 8, 56, and 80%, respectively.

In a third test, Schramm placed thermistors in spoil and measured the change in temperature after 60 s of shade was applied and then again after 60 s of insolation. Temperature drops of 10°C were not uncommon during shading. Temperature increase upon exposure to sunlight was less rapid, though most of the temperature loss was regained in 60 s and generally all by 120 s.

In addition to girdling of stems after emergence, heat killing of seedlings before emergence is a major problem. Further effects of high temperature have been noted by Schramm on seed dormancy, cambial activity, and geotropic behaviour. The reader is encouraged to read the paper for further details.

Elevating the temperature of cold soils was studied in Alaska by McCown (1973). He maintained a 65°C temperature in a 1.2 m diameter pipe buried with 1.2 m of soil cover. Figure 9.2 shows the extent and magnitude of soil warming which resulted under one vegetation zone and Figure 9.3 shows similar effects under different treatments.

The response of native and introduced species, with and without fertilizer, to the heated soil was also studied. As Figure 9.4 shows, heating the soil produced: (1) earlier spring growth and increased total biomass, and (2) accelerated plant nutrient turnover. The response was more pronounced with cultivars than with native species. Thus the greatest fertilization response occurred on unheated soil. Heating had no discernible effect on soil moisture.

9.5 SUMMARY

Physical properties of spoils are difficult to characterize due to problems of reproducibility, lack of standardization, and expense. No well established body of information exists such as for chemical properties.

Texture controls quality of spoils for plant growth. Silt and loam spoils are most productive (good drainage and aeration; high available nutrients; adequate moisture) while clay spoils are least productive (poor drainage and aeration; compaction; surface crust).

Fine texture spoil under coarse spoil may result in perched water tables; conversely, fine material over coarse material may result in saturation of the fine layer.

Particle size distribution of surface material may shift upon extended exposure. Generally, no change occurs below 10 to 20 cm depth.

Structure is very important in spoils. Proper treatment and management of spoils is required to create and maintain optimum structure.

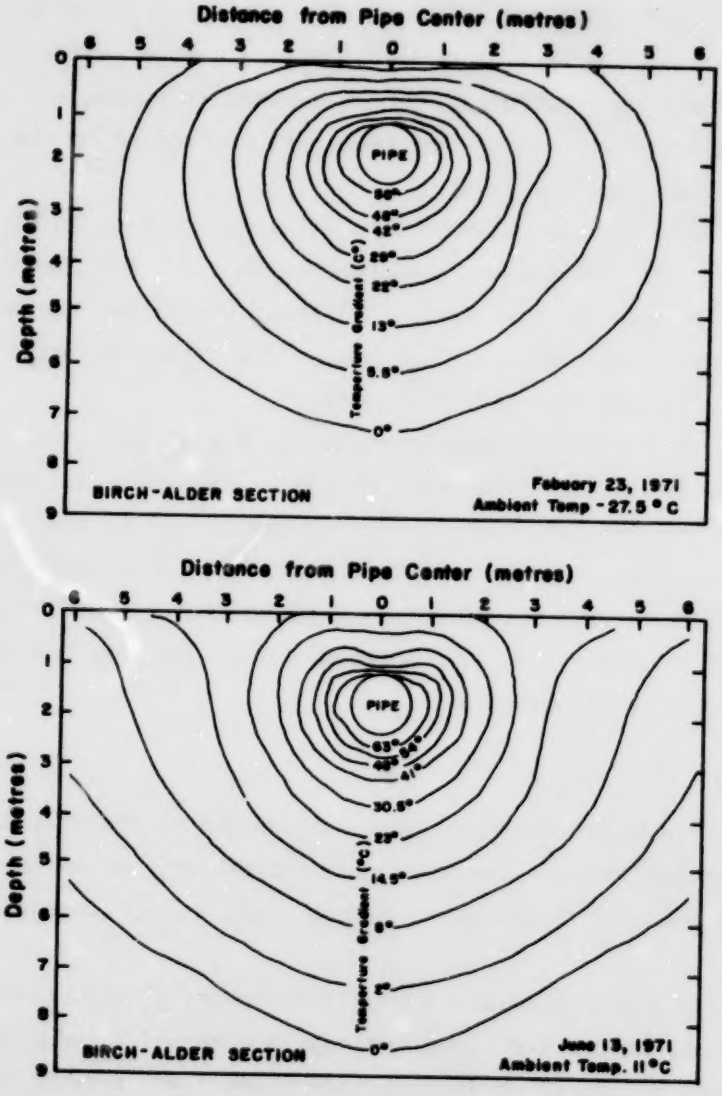

Figure 9.2. Summer and winter thaw bulbs created by a buried, heated pipeline in permafrost soils (Hot Pipe test site, Fairbanks, Alaska). Note that the surface soils over the pipe remained thawed at subzero air temperatures. Interior pipe temperature 60 to 65°C. (Data from Alyeska Pipeline Sevice Company).

Source: McCown (1973)

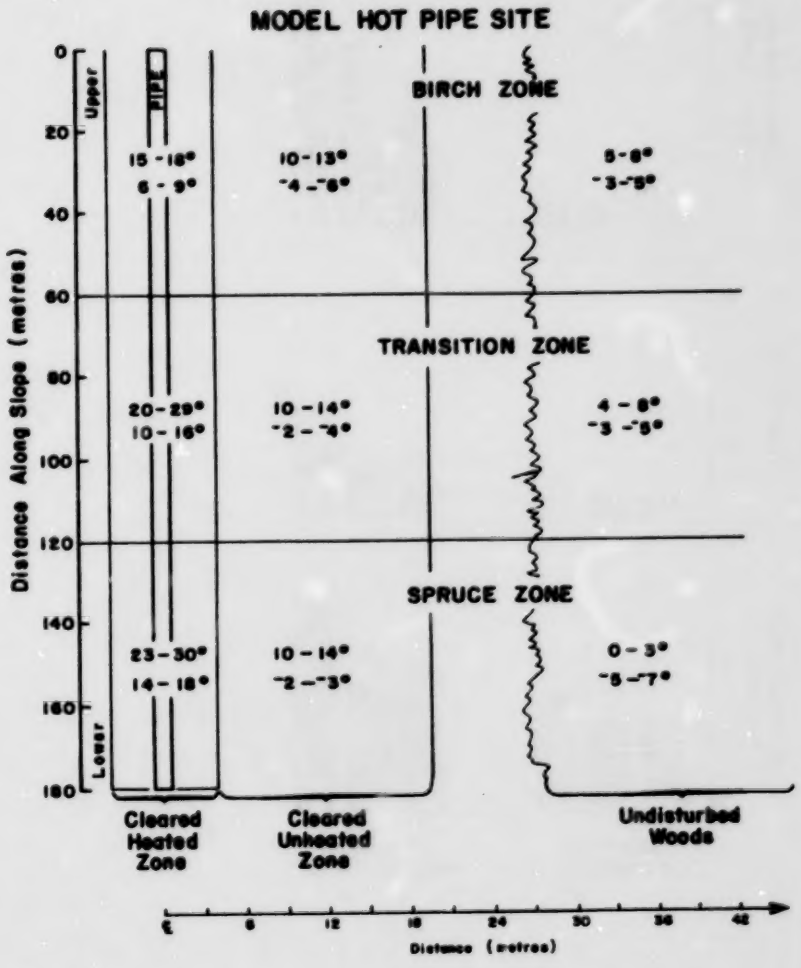

Figure 9.3. A diagrammatic representation of the Hot Pipe site at Fairbanks, Alaska. The site could be divided into two gradients running perpendicular to each other. Each gradient consisted of three zones. Temperatures are maximum (top) and minimum (bottom) soil temperatures 5 cm below surface.

Source: McCown (1973)

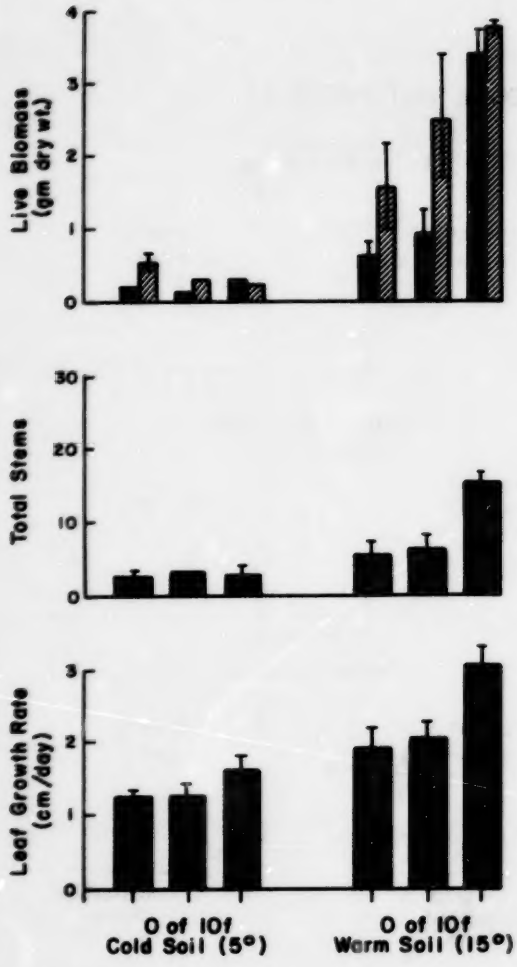

Figure 9.4. The influence of soil temperature and soil ammonium content on the growth and vegetative reproduction of an introduced grass, Manchar brome. Cold soils were highly inhibitory both to growth and production and to ammonium utilization. O, no ammonium added to media; F, ammonium in media equal to North Slope field concentration (0.03 mg/gm media); 10F, 10 times field concentration.

Source: McCown (1973)

Spoil bulk density is usually lower than that of the original overburden. However, use of heavy equipment on spoils may create high bulk density resulting in physical problems and poor plant establishment. High bulk densities result in decreased permeability, decreased moisture storage, and decreased aeration. Proper treatment can reduce bulk density by incorporation of organic material. Physical treatments such as scarification may have only a temporary effect.

Physical spoil factors affect infiltration, moisture storage, and available moisture. The importance of moisture varies with intended crop use. Moisture status is also very important in material handling, engineering stability, and compaction of spoils.

Infiltration of spoil is affected by many physical variables. Sodicity is a primary chemical cause of low infiltration through its effect on spoil aggregation.

Grading of spoils may cause puddling, crusting, and compaction so that infiltration is decreased.

Loose, dry spoil surfaces, or conversely compaction and high moisture content can result in soil temperatures above or below optimum levels, respectively. Slope, aspect and particle size also influence spoil temperature. Surface treatments to create microsites or provide surface cover are often needed to promote vegetation establishment. However, care must be taken as amendments may act as insulators, creating temperatures above or below optimum levels. Once established, vegetation usually creates its own temperature environment.

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10. EROSION

Erosion is one of the most undesirable effects of overland flow. For example, severe erosion and sedimentation in Alberta's Swan Hills by oil industry activity has denuded 12 to 18% of some townships (Wyldman 1971). A recent U.S. Environmental Protection Agency report (1973) discusses the undesirable effects of mining and their solutions. Erosion is greatly accelerated by mining activity and water flow is responsible for much of this. If control includes increased infiltration, groundwater contamination may increase. Remedial techniques include reducing the flow velocity and erodability, revegation, and diversion of flow away from erodable spoil. Erosion control measures including spoil placement and handling of surface water must be planned at the premining stage. Smith and Woolhiser (1978) suggest that modelling may be used to compare different rehabilitation practices; however, more research is needed to determine the relationships between spoil properties and erosion susceptibility. Because the Universal Soils Loss Equation (USLE) was developed primarily for agricultural land, it is not always applicable to strip mined lands. The USLE also does not predict erosion loss where slopes are greater than 5:1 (Gilley et al. 1977; Kirkpatrick, Seith and Allen 1975). The equation is as follows:

$$A = R K L S C P$$

where
- A is soil loss t/ha
- R is rainfall mm
- K is soil erodability - dimensionless constant
- L is slope length m
- C is a cropping management factor (empirical) dimensionless constant
- P is an erosion control practice factor (empirical) dimensionless constant
- S is a slope factor %

Using this equation, Gee, Gilley and Bauer (1976) predicted the effect of slope and vegetation on erosion of recontoured mined land in

western North Dakota (Figure 10.1). Maximum erosion occurred prior to and during establishment of vegetative cover. Losses may be controlled by minimizing slopes and revegetating as soon as possible. Erosion losses can be predicted if the soil physical and chemical properties of the soil are known.

In many moderately rolling to gently sloping agricultural areas the Wischmeier soil loss equation has been used extensively and with significant success both to explain and predict soil loss by water erosion (Voroney, Van Veen and Paul 1981; Van Vliet and Wall 1979; Wischmeier and Smith 1961).

Extrapolation of this methodology to predict water erosion on spoils has not been without difficulty. Gee, Bauer and Decker (1978) found that erosion losses from mine spoils in western North Dakota cannot be accurately predicted by the Wischmeier soil loss equation utilizing measurements of particle size, organic matter, structure, and permeability.

In Wyoming, Lusby and Toy (1976) simulated rainfall with sprinklers on natural sites and on recontoured spoil planted to forage or trees and shrubs. Reclaimed mine sites were more easily eroded than natural sites. The authors concluded that: (1) loam was more desirable than clay, (2) dense root networks were desirable, as was (3) mulching the surface until root networks developed.

In the Swan Hills, erosion associated with oil exploration has been caused by decreased vegetative cover, inattention to runoff control, and the erosive nature of many soil and geologic materials (Wyldman 1971). This problem would be significantly alleviated by revegetation with suitable forage. In England, Downing (1972) reported that erosion control on colliery shale required gradient control to minimize sheet erosion and the more serious gully erosion. The latter was controlled with cut-off drains lined with erosion resistant materials.

Erosion is most important on spoils in high rainfall areas. In south-west Virginia, where rainfalls average 114 to 140 cm/a, sediment and runoff was effectively controlled with valley fills and sediment basins along with re-established vegetative cover (White and Plass 1974). Surface mining increases the erosion hazard by removing vegetative cover, altering

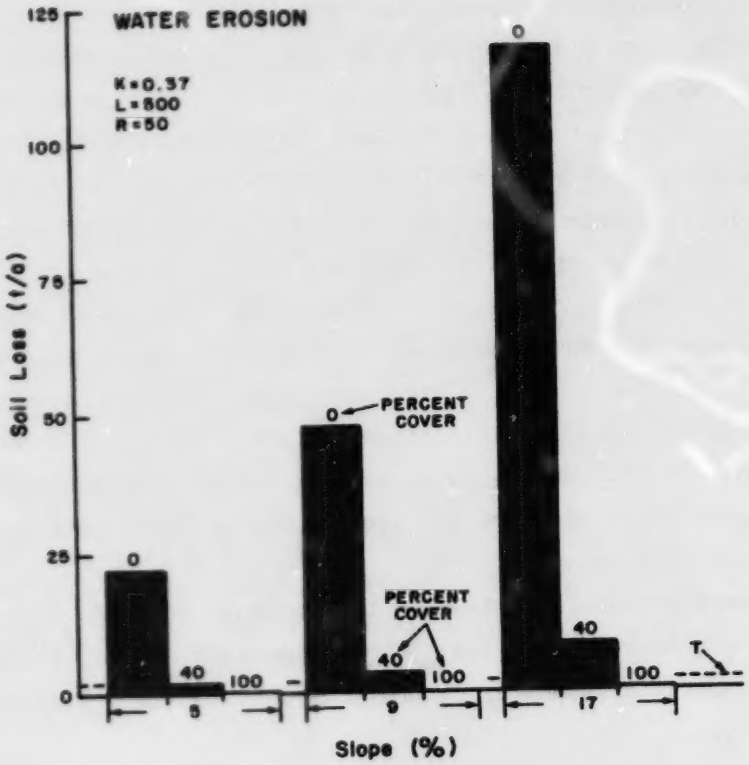

Figure 10.1. Effect of cover on erosion on slopes according to USL Equation with K,L, and R given.

Source: Gee, Gilley and Bauer (1976)

land contours, and frequently by leaving infertile materials on the surface (Robinson 1971).

Also in Appalachia, Curtis reported that erosion and sedimentation were accelerated by strip mining and decreased after mining activity ceased (Curtis 1973). Associated surface disturbances such as haul roads also cause erosion. Land disturbance is a more important factor for erosion than is storm size. Weigle (1965) pointed out that all phases of strip mining produce conditions favourable for erosion. An erosion study of abandoned coal haul roads in eastern Kentucky showed that annual erosion on sandy and clayey silt roads was 6.6 and 12.7 cm, respectively. To allow vegetation to become established on spoil banks, slides and slumping have to be minimized by keeping bank slopes less than the critical angle of repose. Harrison (1974) suggested the term "biological angle of repose" for the maximum slope angle at which plants can colonize, a value of between 25 to 30°. Conversely, Fitzgibbon (1976) reported steep, 30° to 35° stable spoil slopes with significant vegetative coverage from natural colonization (Table 10.1). Mean vegetative coverage on slopes due to natural colonization after 30 years averaged around 50% on slopes greater than or equal to 30° (Table 10.2).

Fitzgibbon's results contradict the commonly held argument that the biological angle of repose is less than the physical angle of repose and that at angles steeper than 25° natural revegetation is not expected to occur (Harrison 1974).

Struthers (1965), in Pennsylvania, suggested that tree planting was preferable to seeding as the initial revegetation on graded spoil. He argued that trees, with their existing root sytems, had a more successful establishment rate than did seeded plants. Grasses subsequently introduced provide a high density ground cover. Vegetative erosion control facilitates profile development in spoil banks. On steep slopes with limited vegetative cover lateral erosion tends to limit organic matter accumulation. Thus, L, F, and H layers are absent and A horizons will not form. Also, lacking vegetative cover, precipitation is lost by surface runoff with very little infiltration. In turn, minimal infiltration leads

Table 10.1. Mean and standard deviation of slope angles for slope facets and age group, Estevan, Saskatchewan.

Age Group	Slope Facet					
	Top		Mid		Bottom	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Late 1960's	17.2°	6.32	32.02°	1.81	8.2°	2.99
Early 1960's	12.3°	2.05	32.62°	3.73	8.6°	4.13
1950's	16.3°	3.8	34.95°	1.66	11.1°	4.45
1940's	9.0°	1.55	30.08°	7.21	11.8°	4.65
1930's	15.75°	4.71	33.23°	3.23	7.7°	2.79

Source: Fitzgibbon (1976)

Table 10.2. Mean percent vegetation for each slope facet and age group Estevan, Saskatchewan.

Age Group	Slope Facet		
	Top	Mid	Bottom
Late 1960's	1%	2%	10%
Early 1960's	1%	1%	17%
1950's	1%	4%	19%
1940's	27%	57%	97%
1930's	47%	41%	89

Source: Fitzgibbon (1976).

to minimal vertical soil solution flux and leaching and deposition of clay and minerals. Thus, B horizons are not likely to develop. A dense surface cover such as grass on steep slopes facilitates organic matter accumulation, infiltration and leaching and thus the development of A and B horizons.

Meiman (1974) discussed revegetation and erosion control in high altitude disturbed lands, including the use of mulches, contour trenches, and channel stabilization. He concluded that since each site had its own specific requirements for erosion prevention, field observation and planning were essential.

In Plains areas, high sodicity causes dispersion and surface sealing which in turn alters erodibility. Erodibility is therefore sometimes greater on spoils covered with topsoil than those without topsoil. For example, some spoils, such as sodic ones, form an erosion resistant crust (Gilley et al. 1977). In this situation, mulching with straw and establishing vegetation as soon as possible is recommended.

Slopes should be restricted in gradient and length and concave in shape. Gilley et al. (1977) successfully developed a modified slope factor (S) for the universal soil loss equation for such sodic spoils; as follows:

$$S = 0.61 + 0.0435s$$

where s is the percent slope

A study to determine the importance of erosion as a controlling factor in revegetation of 30 to 40 year old mine spoils at Estevan, Saskatchewan, was reported by Fitzgibbon (1976). Sheet or wash erosion predominated and rill, gully, and wind erosion were minimal. This resulted in constant slopes (Table 10.1), coarsening surface soil textures with age, fines deposition of 1 to 5 cm/a at the base of slopes (Table 10.3), and in spoil ponds. Despite the significant erosion ($\geq$ 1 cm/yr) on the slopes with limited vegetative cover, natural recolonization gradually increased plant cover to in excess of 50% (Table 10.2), minimizing erosion (Table 10.3).

Table 10.3. Mean net erosion (-) or deposition (in cm) recorded by the erosion pins for each slope facet and age group, Estevan, Saskatchewan.

Age Group	Slope Facet					
	Top		Mid		Bottom	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
Late 1960's	-1.84	1.19	-1.49	0.56	+1.68	1.60
Early 1960's	-0.97	0.51	-0.89	0.40	+5.80	0.78
1950's	-1.66	1.23	0.0[a]	ND	0.0[a]	ND
1940's	0.0[a]	0.69	-0.61	0.60	+1.42	1.22

Source: Fitzgibbon (1976).
[a] or too small to measure

Table 10.4. Total depth of material removed from the surface of the slope for three simulated storms, Estevan, Saskatchewan.

Intensity (cm/h)	Duration (min)	Total depth of material eroded (mm)
1.19	11.5	0.0
2.72	11.5	0.3
4.17	11.5	0.15

Source: Fitzgibbon (1976).

Thus, as plant cover increases on the top and midslope positions from 1% to 2% after 5 to 15 years of colonization (late and early 1960s rows of Table 10.2) to 41% to 57% plant cover after 35 to 45 years of colonization (1930s and 1940s rows of Table 10.2) erosion decreased from a maximum of 1.84 cm to between 1.14 cm and 0.61 cm (Table 10.3).

Rainfall intensity and duration markedly influenced erosion magnitude with individual (simulated) storms capable of removing in excess of 0.15 mm of soil (Table 10.4).

Straw mulch and asphalt emulsions were studied for erosion control. Both treatments minimized erosion (Table 10.5), but the asphalt emulsion also limited infiltration and thus plant moisture availability in moisture deficit prone climates. Conversely, straw mulch increased infiltration and facilitated plant establishment.

In the Swan Hills of Alberta fragile shale and sandstone formations exist and disturbance has resulted in a serious erosion problem that has persisted for the past 20 years. Poor reclamation practice and heavy rainfall have aggravated the problem. Accurate estimates of total actual erosion are apparently not available. Lengelle's (1976) estimates of 2.3 to 4.5 million t/a do not compare with the only other published estimate of 0.1 million t/a. Corrective measures depend largely on stabilizing slopes and revegetation. Although some techniques such as the use of plastic wire mesh, stubble and mulch covers, and terracing were effective in certain situations, overall technical solutions to the problem are not certain.

From an administrative point of view, preventive measures in the Swan Hills should also include thorough geomorphological surveying and mapping of erosion hazard. Further regulations for individual localities based on local features should be formulated and enforced. Vegetation should not be unnecessarily disturbed, and when required, clearing should be carefully planned (Lengelle 1976).

With regards to forested lands, Rothwell (1978) stated that much of the watershed damage is caused by poor timber harvest practices, including tree removal methods, cutting policy, road design, and improper drainage design. The proper design of roads and associated drainage were

Table 10.5. Characteristics of artificial storms and total depth of material removed from the slopes in the mulch test and control experiments, Estevan, Saskatchewan.

Treatment	Intensity (cm/h)	Duration (min)	Total depth of material eroded (mm)
Control	4.17	11.5	0.15
Straw	4.06	11.5	0.06
Asphalt emulsion	3.89	11.5	0.05

Source: Fitzgibbon (1976).

Table 10.6. Back slope and fill slope angles[a] for different soil materials.

Back slopes	Angle	Fill slopes	Angle
Flat ground cuts under 0.9 cm	2:1	Common for most soil types	1½:1½
Most soil types with ground slopes under 55%	1:1	Alluvial soils	2:1
Most soil types with ground slopes over 55%	3/4:1	Ballast	1:1
Hardpan or soft rock	½:1	Clay	4 1:1
Solid rock	¼:1	Rock, crushed	1 ¼:1
		Gravel	1:1
		Sand, moist	1½-1:1
		Sand, saturated	2:1
		Shale	1½:1

Source: Data compiled by Rothwell (1978).
[a] 2:1 = 2 m vertical rise in 1 m horizontal.

discussed in detail. The literature was reviewed and detailed procedures recommended (e.g., Table 10.6).

Nebauer (1973) described detailed, qualitative methods of preventing erosion of road batters (the sloping face of road cuts or fills) in Australia. The discussion was limited mainly to the construction and design aspects prior to the revegetation process. Situations requiring special treatment such as mulching, special contouring, or drainage structures were also described and the importance of vegetative cover emphasized.

10.1 SUMMARY

To implement proper erosion control, planning is needed at the pre-mining stage. While erosion can be predicted to a degree from chemical and physical properties of spoil, more research is required relating spoil properties to erosion potential. Tools such as the Universal Soil Loss Equation and the Wischmeier Soil Loss Equation were developed for undisturbed agricultural land and are of limited value for predicting erosion of mined land spoils.

Erosion is most prevalent in high rainfall areas. However, land disturbance is more important than storm size and erosion can occur during all phases of mining. Associated disturbances such as roads increase erosion. Maximum erosion occurs prior to and during vegetation establishment.

Good soil texture, dense vegetation cover and mulches reduce erosion potential. However, not all mulches and soil stabilizers are compatable with revegetation. Lack of a vegetative cover coupled with erosion slows or prohibits soil profile development and limits organic matter accumulation.

The critical angle of repose for spoil bank revegetation, the "biological angle of repose," is 25 to 30° and is commonly held to be less than the physical angle of repose. However, some evidence contradicts this hypothesis.

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11. CHEMICAL PROPERTIES OF SPOIL/SOIL

Discarded or unwanted geological materials (spoils) associated with the extraction of minerals from the earth rarely provide an environment for plants and animals that is equal to that of natural soils. The inferiority of these unearthed geological materials is due to physical and chemical properties that are inadequate or hostile to plant life.

Chemistry plays a major role in this suitability of the earths' surface for living things. Healthy growth of plants can be expressed largely in chemical terms. The important physical properties of the terrestrial environment for plants may be based largely on chemistry. For example, comparatively large amounts of a monovalent cation like sodium, in relation to the amounts of divalent cations like calcium, will cause clay to deflocculate, seal, and become impermeable to water. The physical droughty condition is a result of the soil chemistry.

11.1 CATION EXCHANGE CAPACITY

Sandoval and Gould (1978) wrote an excellent review article dealing with the characteristics of salt-affected soils, describing some of the unique conditions and how these relate to the unfavourable environment that these soils provide for plants. Cation exchange on the clay and organic fractions of the soil is the dominant exchange process in neutral to alkaline materials. Normally, Ca and Mg are dominant cations in solution and on the exchange complex but with accumulated soluble salts, Na often dominates. When the exchangeable Na constitutes 15% or more of the exchangeable cations, the soil is called a sodic soil. With dominance of Na, the clay becomes dispersed, creating the amorphous, impermeable nature of many of the materials found in strip mine soils. This applies particularly to coal strip mines in the prairie and parkland areas of Alberta.

Coarse textured and usually acidic mine spoils and overburden tend to have low to very low cation exchange capacities of 15 meq/100 g (Dancer 1975; Smith, Tryon and Tyner 1971). In such environments,

leaching cycles controlled by rainfall control the soil nutrient status rather than adsorption and exchange phenomena (Dancer 1975).

Sodic materials can flocculate if leached with water containing calcium salts. By using calcium salt-bearing water, the hydraulic conductivity can be increased and the calcium ion transported to the sites where the Na^+ is exchanged, thus lowering the sodium adsorption ratio.

Doering and Willis (1975) stated that cation exchange relationships may be used to develop an equation for calculating the amount of calcium salt needed to reclaim a sodic soil. Such an assessment should also include the salt concentration of the leaching solution, the percentage of exchangeable sodium, and the soil bulk density. They caution that chemical reclamation of sodic strip mine spoil is costly. For large scale application a better alternative may be covering the spoil with a suitable thickness of non-sodic topsoil.

11.2 pH

The pH is a readily-measured characteristic of the soil that can indicate undesirable conditions. The literature states that pH varies widely in mine spoils depending on geological material, age, climate, and treatment. Breeze (1973) reported that the pH of a chromate ore spoil in the U.K. was 11 or 12. Some copper and uranium mine spoils in the western U.S.A., reported by Peterson and Nellson (1973) have pH values as low as 2. Palmer (1978), in discussing the pH of colliery spoils containing pyrite (in the U.K.) stated that spoils less than one year old are near neutrality but they become increasingly acidic with age. In 10 years, the pH may drop to less than 3. In British Columbia, Lavkulich et al. (1978) reported pH values of about 4 for the tailings at the Sullivan Mine. For the Kaiser Resources Mine (more relevant to Alberta) the pH of the soil is about 6.8.

Graveland (1972) reported pH of 7.8 for great plains spoils from an Alberta mine. Sandoval et al. (1973) reported that pH values can be greater than 8.2 in northern Great Plains strip mine spoils, indicating alkalinity problems.

McCoy, Regier and Graveland (1976) found pH values of 6.0 to 6.5 for the spent tar sands. Regier (1976) reported that pH of the tar sands overburden ranges from about 6.5 for the peat to 7.0 or 7.5 for the mineral material.

In the spent tar sands, it appears the pH pattern is fairly uniform (McCoy, Regier and Graveland 1976; Regier 1976) even though it is weakly buffered. Conversely, in most other spoil and overburden, the pH pattern tends to be complex varying with depth and over time, especially in response to weathering and other pedogenetic alterations of the spoil. For example, in acid coal spoils in the U.K., a typically rapid marked drop in pH from near neutral to a pH of around 2 to 3 within the initial two to three years is followed by a gradual increase over many decades, reaching around 6 after more than 150 years. Pyrite oxidation is one of the controlling factors (Palmer 1978; Down 1975).

Such detailed in situ information on pH dynamics and pH pedogenetic relationships in spoil materials is not yet available for Alberta.

11.3 PLANT NUTRIENT RELATIONS

When land is drastically disturbed, the original soil profile is often destroyed or buried and the underlying geological material or overburden forms the new soil surface. Reclamation then necessitates providing an alternative to natural pedogenetic processes that would or should eventually re-establish a new soil. Geologic overburden from depths below the soil profile that did not constitute the original soil parent material may be exposed at the new soil surface. These materials are often less fertile than the original parent material. This can make soil reclamation and restoration to original productivity levels very difficult.

11.3.1 Nutrient Status

Plant nutrient status of disturbed land is one of the crucial factors determining reclamation success. In the literature, more

attention was given to this aspect of reclamation than any other, suggesting it is perceived as the major reclamation problem.

The very coarse textured spoils in Alberta tend to be deficient in most macro- and micronutrients. The tailings sands in the oil sands area are a good example of this problem. At Syncrude, Regier (1976) reported tailings sand as having only 0.01 and 1.9% total N and P, respectively and only 1.0, 0.8 and 4.0 ppm extractable N, P, and K, respectively (Tables 11.1 and 11.2). At Suncor (GCOS), the tailings sands are deficient in most nutrients with the exception of S (McCoy, Regier and Graveland 1976). The tailings sands at Syncrude lack sufficient Ca, K, NO_3, available P and Zn and contain just enough Cu, Mn, and SO_4 (Regier 1976).

The more finely textured and clay rich soils frequently have macronutrient deficiencies (McCoy, Regier and Graveland 1976; Regier 1976), less frequently micronutrient deficiencies, and may have micronutrient or metal toxicities. In the arid and semi-arid regions of the U.S. and Canadian Great Plains, N and P are usually deficient. On these materials, S deficiency occurs occasionally and the Ca:Mg ratio of >1 can be problematic. Boron and selenium toxicity is a potential problem, especially, for example, in formations with leonardite such as the Sheerness Mine (Bauer, Berg and Gould 1978).

Obviously, such fine textured soils in arid and semi-arid regions tend to have salt and sodium related toxicities as discussed in the preceding sections. If pyrite is present in such fine textured soils, pyrite oxidation will control pedogenesis (discussed subsequently), and if the parent material or rock contains significant metal concentrations, metal toxicities are virtually inevitable. Such metal toxicities are a potential problem in the near neutral and slightly acid spoils in Alberta (Bauer, Berg and Gould 1978).

It is equally clear that most spoil materials in Alberta do not have the toxic heavy metals problems of the acid spoils in humid environments such as south-eastern and central British Columbia, where toxic levels of available Cu, Zn, Pd, and especially Al have been

Table 11.1. Chemical and physical characteristics of spent sand and overburden, for a peat and by textural grouping, Alberta oil sands.

	Spent sand	Peat[b]	Heavy[b] clay	Clay[b]	Sandy Clay	Sandy[b] clay loam	Loam	Sandy[b] loam	Loamy sand	Sand
Number of observations[a]	3	9	4	5	2	14	2	35	1	2
pH	7.7±0.1[c]	6.7±0.7	7.3±0.1	7.4±0.1	7.4	7.4±0.2	7.6	7.5±0.2	7.5	7.5
EC (mmhos/cm)	0.41±0.01	0.41±0.1	1.50±0.67	0.33±0.05	0.94	0.38±0.17	0.28	0.37±0.12	0.37	0.6
SAR	2.6±0.4	0.3±0.1	0.6±0.2	0.3±0.2	0.4	0.4±0.1	0.3	0.4±0.1	0.4	3.0
H_2O soluble cations (me/L)										
Ca	2.1±0.7	3.0±0.8	12.3±5.0	2.4±0.6	8.2	2.8±0.9	2.0	2.6±0.9	2.4	2.4
Mg	0.5±0.1	1.0±0.3	5.1±3.0	0.8±0.1	2.3	0.9±0.3	0.5	0.9±0.4	0.9	2.2
K	0.2±0.0	0.0	0.8±0.5	0.1±0.1	0.3	0.1±0.1	0.1	0.1±0.05	0.1	0.8
Na	2.6±0.1	0.4±0.1	0.8±0.8	0.4±0.2	1.2	0.6±0.3	0.3	0.5±0.1	0.5	5.1
H_2O soluble anions (me/L)										
HCO_3	2.6±0.2	9.8	1.5	-	3.1	3.3	-	3.5	-	3.5
Cl	0.2±0.0	0.2	0.1	-	0.6	0.4	-	0.4	-	3.0
NO_3	ND[e]	ND	ND	-	ND	ND	-	ND	-	ND
SO_4	0.4±0.0	0.8	23.2	-	14.5	8.4	-	13.6	-	-
NH_4OAc ext. cations (me/100 g)										
Ca	0.2±0.0	-	24.4±0.7	24.8±4.6	35.8	23.6±7.0	16.2	10.4±6.2	4.7	2.0
Mg	0.1±0.1	-	9.6±1.5	2.8±1.2	3.7	2.4±0.5	1.4	1.0±0.3	0.8	0.7
K	0.0	-	0.9±0.3	0.3±0.1	0.4	0.2±0.1	0.1	0.0±0.0	0.0	0.1
Na	0.0	-	0.3±0.3	0.0	0.3	0.0±0.1	0.0	0.0	0.0	0.7
$CaCO_3$ equivalent (%)	0.0	-	2.3	1.3±1.2	4.7	2.9±2.8	4.4	1.2±1.4	0.4	0.1

Table 11.1 concluded.

	Spent sand	Peat [b]	Heavy [b] clay	Clay [b]	Sandy clay	Sandy [b] clay loam	Loam	Sandy [b] loam	Loamy sand	Sand
Number of observations [a]	3	9	4	5	2	14	2	35	1	2
CEC (me/100 g)	0.2	-	41.1±3.3	18.6±3.0	15.7	12.8±1.8	8.2	5.4±1.2	4.4	3.5
N (Kjeldahl, %)	0.01	1.12±0.12	0.04±0.01	0.04±0.01	0.05	0.04±0.01	0.04	0.03±0.01	0.01	0.01
NO_3-N (ppm)	-	8.3±4.0	6.0±0.7	4.7±0.4	4.2	4.4±0.6	3.7	4.6±0.8	5.9	5.1
P (ppm)	1.9±0.2	0.8±0.7	0.3±0.2	1.2±0.4	0.1	1.4±1.4	0.8	1.2±1.1	0.8	9.5
Cu (ppm)	0.2	0.7±0.5	3.9±0.7	1.6±0.6	6.7	1.0±0.6	0.6	0.6±0.2	0.2	2.0
Fe (ppm)	5.5	480±315	87±8	25±7	140	55±35	10	40±30	50	25
Mn (ppm)	1.0	33±45	6.0±1.1	1.7±0.6	7.7	5.3±4.1	23	4.4±2.6	8.0	4.7
Zn (ppm)	0.4	2.4±2.6	2.5±2.5	0.4±0.0	2.4	0.3±0.1	0.5	0.4±0.2	0.2	0.2
Specific surface (m^2/g)										
Soil	6±1	-	-	60	92	-	74	22	-	5
Clay (<2μ)	80±10	-	-	135	270	-	210	105	-	310
Available moisture (%)	1.2±0.4	-	14±2	11±2	11	11±1	12	8±2	3	3
Saturation %	43±6	240±55	77±4	55±11	50	44±6	41	34±3	24	26

Source: Regier (1976)

[a] Excludes samples with EC values greater than 2 mmhos/cm and/or SAR values greater than 6.

[b] Based on approximately 80% of the number of observations.

[c] Standard deviation of the mean.

[d] Excepting spent sand, determined only for those samples with EC values greater than 0.8 mmhos/cm.

[e] ND, not detectable.

Table 11.2. Chemical and physical characteristics of some materials available for reclamation of spent sands, Alberta oil sands.

Material	pH	E.C. (mmhos/cm)	SAR	Ca	Mg	Na	SO_4	Cl	HCO_3	Total N	NO_3-N	P	K
				Saturation Extract p.p.m.							available p.p.m.		
Soil Ae	6.0	0.17	0.2	10	4	3.0	7	3.5	30	400	1.5	16	31
Bf	6.4	0.10	0.4	4	2	3.9	15	0.7	30	200	1.5	7.5	16
C	6.6	0.10	0.5	4	1	4.6	8	trace	30	100	1.5	3.5	-
Peat GCOS	6.3	0.48	0.6	59	7	18	57	trace	189	9 600	3.0	0.6	55
Syncrude	6.3	0.25	0.2	38	6	5.3	57	trace	85	11 400	3.5	0.6	-
Raw Sedge	6.0	0.56	0.2	71	16	8.5	67	7.1	219	19 700	13	36	-
Raw Sphagnum	4.1	0.40	0.9	5	25	9.2	20	12	0	7 900	13	41	1800
Overburden GCOS Waste Dump #5	6.3	5.06	7.0	266	164	591		3.5	-	600	4.8	4.8	-
Overburden GCOS Waste Dump #7	6.3	3.14	1.3	273	145	103		-	-	500	1.3	1.4	-
Overburden Syncrude Till #1	6.4	0.17	0.6	8	4	7.8	16	5.3	39	300	1.8	2.3	47
Overburden Syncrude Till #2	6.2	0.30	0.5	18	8	9.2	18	1.8	122	300	1.5	13	-
Spent sand GCOS	6.6	0.70	0.9	47	27	32	177	trace	134	100	1.0	0.8	4.0
Lean Oil Sand	6.4	1.01	2.2	52	28	80	331	21	54	600	1.8	11	7.8

continued

Table 11.2. Concluded.

Material	Texture (hydrometer) % Sand	% Clay	% Silt		Density (Disturbed sample)	Hydraulic conductivity (cm/h)	Field Capacity (%)[a]
Soil Ae	98	trace	2	S	1.5	80	12
Bf	98	1	1	S		250	10
C	99	0	1	S		280	8
Peat GCOS					0.25		130
Syncrude							250
Raw Sedge					0.1		310
Raw Sphagnum					0.05		570
Overburden GCOS Waste Dump #5	70	14	16	SL	1.3	30	30
GCOS Waste Dump #7	59	16	25	SL	1.4	13	25
Syncrude Till #1	62	16	22	SL		8	16
Syncrude Till #2	62	16	22	SL	1.5	6	19
Spent Sand GCOS	99	0	1	S	1.4	100	25
Pilot	97	1	2	S		150	
Lean oil sand						250	1.0

Source: McCoy, Regier and Graveland (1976)

Note: Lack of numerical value refers to insufficient sample. Some variation in salinity. Authors suggest extensive sampling and analyses of those materials prior to their inclusion in a reclamation plan.

a Gravimetric method

reported (Lavkulich et al. 1978). Conversely, many Alberta spoils do not have the advantages of spoils in the more humid environments such as in British Columbia, the U.K., and eastern North America. In these latter spoils, enhanced by clay, micronutrients are rarely limiting, rooting depths are extended, N accumulates (Lavkulich et al. 1978; Doubleday 1972; Smith, Tryon and Tyner 1971) and macronutrients levels in some cases may approach or exceed those in adjacent natural soils (Lavkulich et al. 1978; Grube et al. 1974). However, studies of plant nutrient deficiencies in mine spoils in the humid south-eastern U.S. (Grube et al. 1974; May et al. 1973) indicate that apparently these spoils deteriorate in K, P, Ca, and Mg sufficiency with age. The highly variable chemical characteristics of the overburden and spoils limit extrapolating this information to Alberta.

11.3.2 Nutrient Interactions

On clay rich shale coal mining spoils in the U.K., Doubleday (1972) reported that K status was increased with liming. Although K increased grass yields on red shales, it depressed yields on black shale spoil. Ignition increased both P fixation and P fertilizer requirements. Phosphorous fertilizer requirements also increased as soil pH decreased. Due partly to the clay rich nature of the spoil, macronutrients and trace elements were not noticeably deficient.

In his work on acid coal spoils in the U.K., Palmer (1978) discussed the effect of pH on variations in levels of exchangeable Ca, Mg, Na, and K but recognized that differences in CEC also had an effect. He found P deficiency to be the primary limiting factor to plant growth. He also found acid dissolution of $MnSO_4$ could cause Mn toxicity.

Gemmel (1975) and Breeze (1973) reviewed the toxicity and reclamation problems of Cr ore mine spoil in Lancashire, U.K. Toxicity was due to the very high pH of 10 to 11 and excessive levels of Cr, SO_4, HCO_3^-, and EC in general. Of the various reclamation alternatives shown in Table 11.3, covering spoil with subsoil and incorporating this with organic substrate was the most feasible solution. In this situation

Table 11.3. Reclamation alternatives for Cr spoil in the United Kingdom.

Amendments	Rate	Method	Effects	Recommendations
(a) Chemical liming	10 t/ha	surface incorporation	increase Cr solubility lower pH, EC	unsuitable due to Cr toxicity
$FeSO_4$ $7H_2O$	$\leq$40 t/ha	surface incorporation by disking or harrowing	reduces Cr level, lowers pH	too expensive to be feasible
b) Substrates porous subsoil	25 to 30 cm depth	spread on surface of spoil. No mixing.	dilutes toxic levels reduces upward toxin mobility	Combine both types of substrate amendments to achieve the most feasible reclamation solution.
organic matter as peat or sewage sludge choice depends on availability and costs.	$\geq$100 t/ha	surface incorporation disking	metals form organ-metallic complexes reducing levels of plant available metal toxins.	

Source: Adapted from Gemmell (1975)

liming to lower the pH was not feasible as it would increase Cr solubility.

In the western U.S. (Utah, Montana, Colorado, Arizona, New Mexico) where spoils acidify due to pyrite oxidation, toxic levels of B, Ca, Fe, Mn, and pH are common as well as NPK deficiencies (Peterson and Nielson 1973, 1978). In toxic situations more than one element is usually involved in synergistic or antagonistic effects. Minor element deficiencies can be induced when the soils are amended to correct heavy metal toxicities. For example, micronutrient deficiencies could be induced in Alberta spoils by amending to raise soil pH or available P.

Copper/molybdenum problems have been studied in coal mine spoils in the northern Great Plains of the U.S. (Erdman, Ebens and Case 1978). The Cu:Mo ratio presented no problem if >6:1. Lower ratios resulted in physiological stress of livestock fed or grazed from forage on these soils. Increased Mo uptake by plants and potential livestock Mo toxicity occurred in alkaline soils and with legumes, especially Melilotus sp., which tended to accumulate Mo.

In greenhouse experiments, Reeder and Berg (1977) compared N availability from added NH_4^+-N and indigenous N in Cretaceous shale, fresh coal spoils, vegetated coal spoils (five years Medicago sativa), and normal soil, all from the Seneca mine, near Hayden, Colorado. The materials were moistened to field capacity and either incubated at 19 to 25°C for 21 days or not incubated. Hordeum vulgare was the test crop. They found that availability to the plants of indigenous N was less in the shale and spoils than in the soil.

Incubation of the fertilized shale and spoil decreased the uptake of N but had no significant effect on the uptake of N from the unfertilized or fertilized soil. Nitrogen uptake from the vegetated spoil approached uptake from the soil, indicating that with vegetation cover and relatively short time, N cycling in geologic materials may approach the N-cycling properties of soil.

11.3.3 Pedogenesis of Nutrient Status

Little is known about long-term changes in nutrient status of spoils in Alberta so inferences are drawn from research outside the

province. This role of pedogenesis in spoil reclamation is discussed in more detail in Chapter 13.

Initially, most spoils, including those in Alberta and the more humid east coast and U.K. environments, are low in organic matter content and have a poor structure (Grube et al. 1973). In certain environments these properties would be expected to accumulate and develop slowly over many decades (Down 1975).

Conversely, the forms and availability of P do not tend to increase as acid spoils age (Palmer 1978; Doubleday 1972). Instead weathering releases Fe, Al, Ca, and Mg clay minerals which precipitate or fix soluble P forms (Pulford and Duncan 1975). Such trends, however, are not without exceptions. For example, one study on acid coal shale spoil in Colorado reported fertilization on spoil was less efficient than on adjacent natural soils (Reeder and Berg 1977). Presumably fertilizer N was less available to plants grown in spoil than plants grown in natural soils. Thus, fertilizer NH_4 added to fresh shale, fresh spoil, and spoil vegetated for five years, appeared to be less available to Hordeum vulgare with time than the same amount of fertilizer N added to natural soil (Table 11.4). It is possible this particular study reflected only a short-term phenomenon and not the long-term trend. Such long-term data have not yet been gathered for spoils typical of Alberta so as to assess the importance of this to reclamation success.

Lodhi (1979) studied changes in number of nitrifying bacteria and nitrogen form in coal spoils of various ages, near Velva, North Dakota (see Chapter 12.1.1 for more details). Spoil ages were 0 (freshly deposited), 1 to 3, 7 to 9, 17 to 19, 30 to 32, and 45 to 47 years old. An unmined site represented a climax community.

The author found that ammonium content increased with age of spoil while nitrate decreased (Figure 12.2). Spoil pH was higher for all ages than the unmined soil (8.0 to 8.4 versus 7.5). Calcium and magnesium showed gradual decreases from newly mined spoil to successional stages. Calcium levels were substantially lower in the

Table 11.4. Uptake of N and percent recovery of fertilizer N by barley in greenhouse studies in western North Dakota.

	N uptake (mg/pot)		% Recovery of fertilizer N[a]	
	Nonincubated	Incubated[b]	Nonincubated	Incubated
Shale	12.9	13.3	68.9	52.9
Fresh Spoil	9.8	10.9	73.2	46.2
Spoil Vegetated for five years	21.9	25.1	63.2	48.8
Soil (undisturbed)	20.0	21.6	61.8	59.3

Source: Adapted from Reeder and Berg (1977), Soil Science Society of America Journal, Volume 41, 1977, pages 919-921, by permission of the Soil Science Society of America.

[a] N applied at 84 mg/pot

[b] Incubated for 21 days at 19 to 25°C and watered daily to field capacity prior to transplanting barley seedlings.

unmined soil. Phosphorus levels showed an increasing trend through the successional stages. The unmined soil had substantically more P than the mined soils. Potassium showed no consistent trends with age.

11.3.4 Characterization Of Nutrient Status

In lieu of long-term studies on nutrient release and availability, limited characterization of spoil and overburden materials in Alberta or of materials similar in nature to those in the province has occurred. The rationale behind characterizing overburden before mining and comparing it to adjacent undisturbed soil and post mining spoil is ultimately to be able to predict yield differences between spoil and adjacent natural soils and amend the spoil so yield depression is eliminated. By characterizing the physical and chemical properties of the soil and the overburden one can predict whether the nutrient status and the physical medium of the mining spoil, whose chemical properties should closely approximate those of the overburden, will be more favourable or detrimental to plant growth or survival. In this case, soil is defined as the naturally occurring, unconsolidated mineral or organic material at the earth's surface that is capable of supporting plant growth. It extends from the surface to 15 cm below the depth at which properties produced by soil-forming processes can be detected (Agriculture Canada 1976:39). Overburden is the material between the soil and bedrock which is to be mined.

This approach can be developed into rating systems of soil and overburden suitability for reclamation, similar in principle to land use capability systems. Efforts to do this are discussed in detail in Chapter 14. Sandoval et al. (1973) provided a sample of one of these systems.

These authors reported on the chemical characterization of spoil and its evaluation at several coal mine sites in western North Dakota. Overburden pH was moderate to strongly alkaline with high saturation percentages (Table 11.5). Although the overburden was not highly saline, Na was the dominant cation, giving high SAR values and

Table 11.5. Chemical characteristics of overburden at three sites in western North Dakota before disturbance by mining.

Sites	Depth (m)	pH	Sat (%)	EC (mmhos)	SAR
1. Stanton level site	0 to 2	7.6	70	1	1
	2 to 11	7.6	46	2	1
	11 to 20	7.4	86	5	7
	20 to 98[a]	≥6.8 to 8.5	≥122	≥1	≥15
2. Stanton hilly site	0 to 3	7.0	50	2	2
	3 to 10	8.2	128	8	13
	10 to 18	8.0	181	5	15
	18 to 109[a]	≥4.5	≥142	≥2	≥22
3. Golva[b] site	0 to 20	7.7	87	3	2
	20 to 40	7.9	95	1	9
	40 to 80	7.6	95	3	25
	80 to 120[a]	7.9	174	2	50

Source: Adapted from Sandoval et al. (1973)

[a] Layers with lignite.

[b] Sampling by courtesy of U.S. Forest Service, Dickinson, N.D. The lithologic log shows major lignite layers at 34.7 to 36.6, 85.3 to 91.4, and 103.6 to 121.9 m.

indicating moderate to highly sodic conditions. The chemical characteristics became less suitable for reclamation with increasing overburden depth. The characteristics of the surface material of spoil piles, derived from overburden as indicated in Table 11.5, were markedly less fertile to those of adjacent or local topsoil as Table 11.6 illustrates. Thus, such spoil in and of itself would be unsuitable for reclamation. It would be amended or covered with more fertile material to be successfully reclaimed.

11.4 SPECIAL PROBLEMS

Many spoils are extremely toxic in that fertilization or minor chemical treatment will not ameliorate them. Usually, these spoils are either of very low or very high pH. For clarity and ease of discussion in the subsequent sections, a number of commonly used terms are defined as follows:

1. Exchangeable sodium percentages. The extent to which the adsorption complex of a soil is occupied by sodium, it is expressed as (Agriculture Canada 1976):

$$ESP = \frac{\text{exchangeable sodium (meq/100 g soil)}}{\text{cation exchange capacity (meq/100 g soil)}} \times 100$$

2. Cation exchange capacity. The total amount of exchangeable cations that a soil can adsorb. It is sometimes called "total exchange capacity," "base exchange capacity," or "cation adsorption capacity." It is expressed in milliequivalents per 100 g of soil (or of other adsorbing materials such as clay) (Agriculture Canada 1976).
3. Electrical conductivity. The electrical conductivity or specific electrical conductance of a solution is the reciprocal value of its specific electrical resistance.

Table 11.6. Chemical characteristics of normal topsoil and surface mine spoils from strip mined areas in western North Dakota.

	Stanton ND		Zap ND	
	Topsoil	Spoil	Topsoil	Spoil
pH	6.8	8.3	7.3	8.8
Saturation %	43	150	36	119
EC (mmhos)	<1	2	<1	2
SAR	<1	23	<1	43

Source: Adapted from Sandoval et al. (1973)

The latter is the resistance of a "column" of the solution with a cross-section of 1 cm^2 and a length of 1 cm. Hence, the specific electrical resistance is expressed in ohm cm^{-1} cm^2 or ohm cm and its reciprocal value in ohm^{-1} cm^{-1}, which is generally written as mhos cm^{-1}. In practice the EC-value is given in millimhos cm^{-1} (mmhos cm^{-1}) or sometimes micromhos cm^{-1}. Obviously the salt concentration is only approximately defined by the EC-value, mainly because the mobilities of different ions are only approximately the same. However, for practical purposes a rough estimate on the basis of EC-values often suffices (Bolt and Bruggenwert ed. 1976:173).

4. Sodium adsorption ratio. This ratio is useful in relating the concentrations of cations in solution to exchangeable cations. SAR is calculated as follows (McKeague 1978:71):

$$SAR = Na^+ / \sqrt{(Ca + Mg)/2}$$

where Na^+, Ca^{2+} and Mg^{2+} concentrations are expressed in meq/L.

Electrical conductivity can be used to estimate total salt concentration in the soil solution as follows:

$$c = EC_e \times 10^1$$

between 10^{-3} and 10^{-1} N soil salt solutions
where c is the concentration in solution N or meq/ml.

EC_e is the electrical conductivity of the saturation extract in mmhos/cm

Also the sodium adsorption ratio can be related to exchangeable sodium percentage as follows (Bolt and Bruggenwert ed. 1976:180):

$$\frac{ESP}{100-ESP} = 0.015\ SAR$$

11.4.1 Acidity

Discussion of acidity forms a large part of the literature on colliery spoil reclamation in the U.K. and south-eastern U.S. It is also important in the metal mining spoils of the western U.S. In the literature reviewed from the Great Northern Plains or the Canadian Plains there was little mention of acidity. Only the Canadian citation on the Sullivan Mine tailings of British Columbia reported serious acidity.

In pyritic colliery spoils in the U.K., Palmer (1978) reported that acidity develops over time. Ten years were required to reach a pH of 3 (although he did not report the original pH), with the rate of acidification dependent on pyrite content. Down (1975) also reported pH dynamics over the first 150 years of spoil pedogenesis (see also Chapter 13). In this study acidity increased for the initial decade, remained constant for four decades, and then slowly increased towards neutrality for the next five decades. Little change was noted subsequent to this.

Peterson and Nielson (1978) reported that spoil materials from metal mining in Utah developed acidity due to oxidation of sulphides of Cu and Fe, which in turn increased the solubility of heavy metals and lowered the quality of the spoil with time.

Smith et al. (1974) reported that areas of old mine spoils in West Virginia not supporting vegetation had pH values less than 3.7. On vegetated areas the pH value exceeded 3.8. Copper and uranium mining spoils in the western U.S. were strongly acid from pyrite oxidation (Peterson and Nielson 1973). In these spoils, acidity, salt, and heavy metal levels in solution increased with time.

11.4.2 Alkalinity

In the plains area of Alberta, mine spoils are usually alkaline rathern than acidic. Extreme alkalinity (pH as high as 8.9) of Northern Great Plains spoils was reported by Sandoval et al. (1973) but not to the extreme reported in some other areas. Chromate ore spoil in Britain can have a pH of 11 to 12 according to Breeze (1973). Both

he and Gemmel (1975) report chromium toxicity to be a major problem on chromium ore mine spoils.

The mineral overburden of the Alberta tar sands is usually neutral to slightly alkaline, although the peat deposits are moderately acidic (Tables 11.1 and 11.2; McCoy, Regier and Graveland 1976; Regier 1976). The more strongly alkaline of these materials are not suitable surface substrates for reclamation.

In practical terms, the distinction between alkalinity and sodicity is not large. In Alberta most alkali or sodic spoils are non-saline and are thus low in total salt concentration (E.C.). These materials are thus defloculated and have low hydraulic conductivity.

11.4.3 Salinity

Sandoval and Gould (1978) provided a detailed review of the nature and management of saline soils. Soluble salts in arid and semi-arid areas are released to groundwater by weathering of primary minerals, accumulating in areas of groundwater discharge. These salts primarily include: Ca^{++}, Mg^{++}, Na^{+}, SO_4^{-}, and Cl^{-} with smaller amounts of K^{+}, HCO_3^{-}, CO_3^{-}, and NO_3^{-}.

Saline soils contain mainly neutral salts: Cl_2^{-}, SO_4^{-}, Ca^{++}, Mg^{++}, and Na^{+}, with Na^{+} representing less than half the soluble cations. Gypsum and lime may also be present. They are empirically classified as having a saturation extract EC >4 mmhos/cm. The degree of salinity hazard has been empirically defined by the USDA soil survey (Table 11.7).

Saline soils contain sufficient salts for growth of most plants. However, they tend to form less water stable aggregates and are more susceptible to puddling and deflocculation during rainfall events. They often display white surface crusts and are associated with stunted plant growth and unusually dark green leaves with tip burn or marginal burn.

Table 11.7. Expected salt effect on crop growth, as a function of the concentration in the saturation extract.

EC_e (mmhos/cm)	0	2	4	8	16
Effect on crop	Salinity effects mostly negligible	Yields of very sensitive crops may be restricted	Yields of many crops restricted	Only tolerant crops yield satisfactorily	Only a few very tolerant crops yield satisfactorily
Concentration of saturation extract (normal)	0.0	0.02	0.04	0.08	0.16
Osmotic pressure (bar)	0	1	2	4	8
Proposed classification	non-saline	slightly saline	moderately saline	very saline	extremely saline

Source: Data compiled by Bolt and Bruggenwert (1976)

Saline sodic spoils are defined as having an EC > 4 mmhos/cm and an ESP >15.

The salt accumulation influences plant growth primarily by limiting water availability (an osmotic effect) and, rarely, by causing plant toxicities. More than other salts, Na_2CO_3 generates very alkaline pH and high osmotic potentials, limiting plant water availability. Toxicities associated with saline spoils are normally due to ions such as Cl^-, and sometimes B. The high pH inhibits the solubility and plant uptake of P fertilizer.

As is well known, clay and organic matter contribute most of the cation exchange capacity of the soil. In saline soils, Ca and Mg are the dominant cations in solution and on the exchange complex. As salts accumulate in dry environments, precipitation of Ca and Mg carbonates and sulfates occurs. Sodium, a more mobile ion, may become the dominant cation in solution. It gradually replaces Ca and Mg on the exchange complex. Sodium must comprise about half or more of the soluble cation concentration before appreciable amounts are adsorbed by the exchange complex. As the Na adsorbed on the exchange complex increases, the soils become more sodic (see Section 11.4.4).

As was previously mentioned, salinity is commonly estimated from the EC of the soil solution (Sandoval and Gould 1978; McAllister 1977; Kieffer 1972); however, EC overestimates salt and osmotic potential for pH < 4 and >10 (Berg 1978). McAllister (1977) gave some examples of Alberta plains overburden with low and high salinity and suggested some practical solutions, including dilution with low-salt materials.

Tar sands overburden is usually only slightly saline with EC <2 mmhos/cm (Regier 1976; Tables 11.1 and 11.2). In the western U.S., copper and uranium mining spoil are high in salt (Peterson and Nielson 1973). Salts from the ore bodies are dissolved in the processing water and are concentrated in the water by recycling.

Usually some salt must be leached from these mine spoils before revegetation. In Ohio, Struthers (1965) studied leaching of spoils in 1.2 m deep lysimeters. In four years, as much as 291 t of salt per hectare (19g per kg of spoil) was leached by natural precipitation. The minimum salt leached was 1.0 t/ha. The most salt was removed from toxic spoils having pH < 3.0. Where pH < 3.0 or was alkaline, salt yield was not influenced by the type of spoil.

The breakdown in aggregate structure, in addition to affecting plant growth and tilth, can also increase erosion potential as was reported in strip mine spoil near Drumheller, Alberta (Graveland 1972).

11.4.4 Sodicity

As mentioned in the preceding section, when sodium comprises about half or more of the soluble cation concentration, Na begins to be adsorbed on the exchange complex in significant quantities causing the soils to become increasingly sodic (Sandoval and Gould 1978). Sodic soils are defined by the U.S.D.A. as having an ESP >15 mmhos/cm (Sandoval and Gould 1978). Soil pH is usually alkaline and Na may cause adverse physiological effects. The dominant cation is Na, and the main anions are SO_4, HCO_3, Cl. Appreciable levels of CO_3 occur when pH >8.5. Above pH 8.5, Ca and Mg are for the most part precipitated as carbonates. The Na adsorbed on the exchange complex interferes with water stable aggregate formation and consequently the soils are subject to puddling and deflocculation during rainfall events, and to surface crusting and large vertical cracking during dry periods. This tendency to disperse or deflocculate when wet means hydraulic conductivity is very low and varies inversely with ESP.

In addition to the other adverse effects on plant growth and nutrition in saline soils, NO_3 formation appears to be limited in sodic soils (Sandoval and Gould 1978).

In practical applications, ESP and SAR have been widely used as an index of sodicity or sodium activity of a spoil or soil (Sandoval

and Gould 1978; McAllister 1977; Sandoval et al. 1973). SAR and ESP are usually highly correlated in saline and sodic soils (Sandoval and Gould 1978), however there are exceptions (Berg 1978). At SAR values >12 to 15 soils tend to exhibit physical problems (McAllister 1977; Sandoval et al. 1973). Overburden in North Dakota coal fields and most spoils in North Dakota, Wyoming, and Montana have SAR values >12 (Sandoval et al. 1973). Klesse (1977) reported SAR levels of overburden and soil for one coal mining site at Popular River in Saskatchewan. Overburden SAR was very low, ranging from 0.08 to 0.4 and the overlying soil (not described) ranged from 0.1 to 2.6. Mickleborough (1977) reported SAR levels of coal overburden and soils for the Souris Valley Coal Mine in Saskatchewan. The SAR levels in the soil ranged from 0.3 to 23.2 and were highly variable over short distances. Although not described, the soil chemical analysis suggests these soils are Solonetzic. The overburden SAR levels ranged from 10 to 17 near the surface to between 25 and 37 near the coal seams.

Shaneman (1977) reported SAR and ESP levels of typical overburden in the agricultural plains areas of Alberta. In may Solod soil areas, overburden layers are not limiting to crop productivity (Figure 11.1). Underlying typical alkaline Solonetz soils most of the overburden has SAR and ESP levels which make it unsuitable for reclamation to agriculture (Figure 11.2). In this example only the coarse till under the soil has low SAR and ESP levels. Underlying a typical Black Solonetz all materials from the B horizon and deeper are excessively sodic (Figure 11.3).

Monenco Consultants Limited (1983) reported SAR values for soil and minespoil at the experimental soil reconstruction site in the Highvale coal mining area. Soils were predominately Gray Luvisols and Orthic Humic Regosols interspersed with some Dark Gray Luvisols in depressional areas. These soils were all developed in glacial tills. Some Brunisols on coarse textured sands from the Paskapoo or Edmonton formation were also described. Average measured topsoil SAR of reconstructed soils, made from the previously described undisturbed

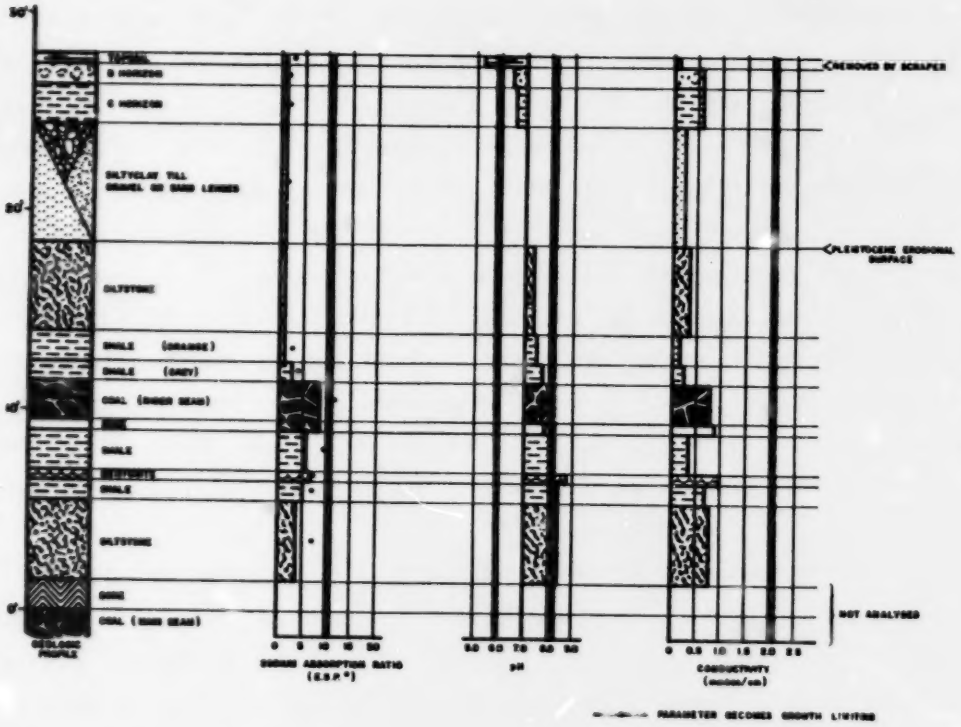

Figure 11.1. Typical overburden under a "Solod" soil in the central Plains region of Alberta.

Source: Shaneman (1977).

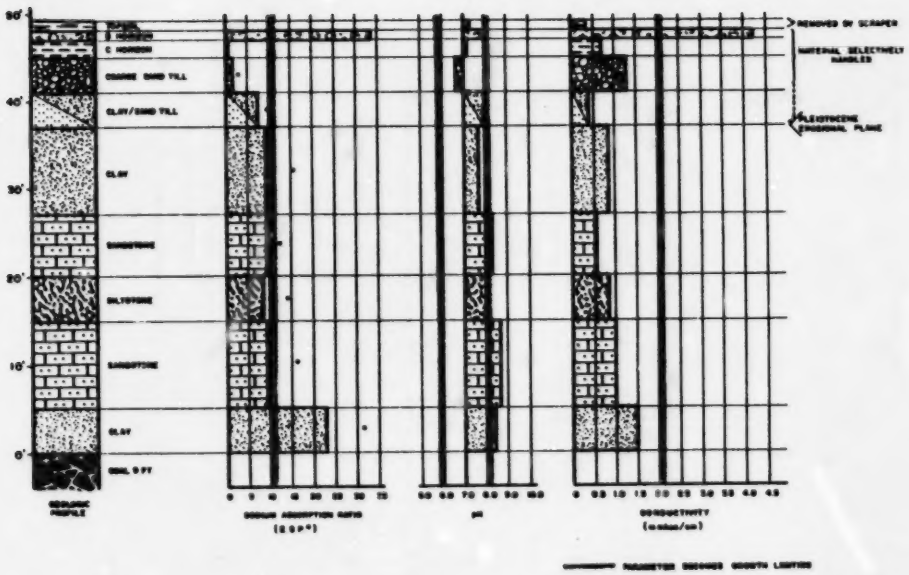

Figure 11.2. Typical overburden under an "Alkaline Solonetz" soil in the Plains region of Alberta.

Source: Shaneman (1977).

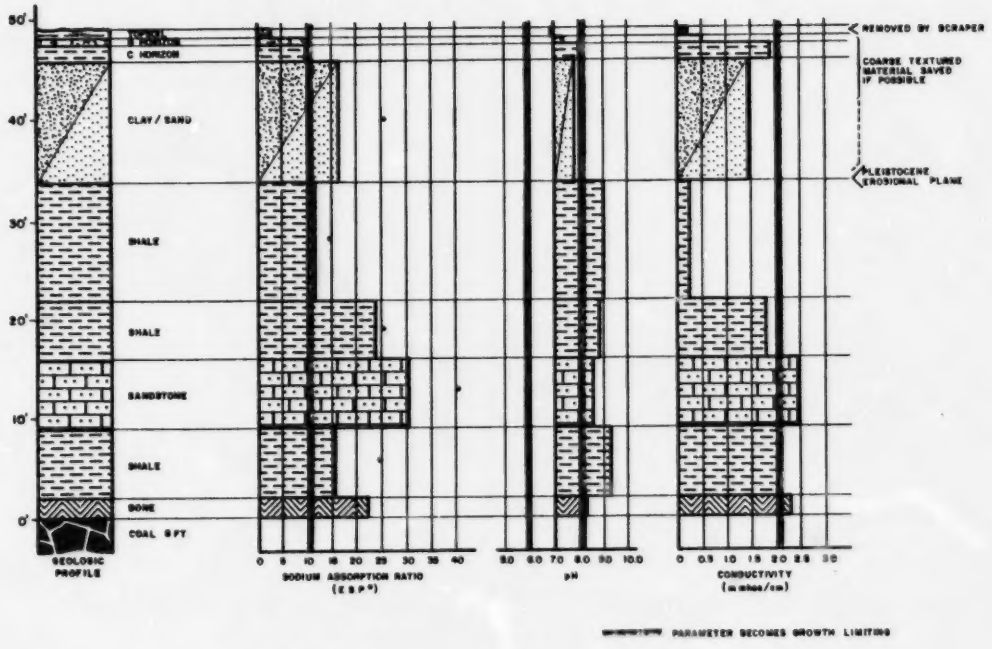

Figure 11.3. Typical overburden under a "Black Solonetz" soil in the Plains region of Alberta.

Source: Shaneman (1977).

soils, ranged from 0.10 to 2.28. Subsoil SAR levels from the same soils ranged from 0.36 to 0.97. The mine spoil tended to be highly sodic when measured in situ with average levels of ESP = 40 and SAR = 21. In the reconstructed soils, SAR of the mine spoil immediately below the soil ranged from 16 to 24.

Parker (1981) reported even higher coal overburden SAR levels at Battle River, Alberta. At 0 to 60 cm spoil depth SAR ranged from 22 to 53.

Graveland (1972) reported fairly low SAR values averaging 15.4 in the coal spoil formed from shales, sandstones, and ironstones near Drumheller, Alberta.

Possible techniques for reclaiming or ameliorating saline, sodic, and saline/sodic soils and spoils include:

1. Covering saline and sodic spoils with non-sodic, non-saline, soil.
2. Installing drainage to lower water tables and enhance leaching.
3. Leaching of excess soluble salts by irrigation or spraying.
4. Replacing exchangeable Na directly or indirectly by leaching with divalent cations.
5. Improving soil structure by deep ploughing, ripping, and use of chemical structure modifiers.
6. Improving soil structure and/or chemical balance by mixing in amendments, lime, sulfur, non-sodic or saline soil or calcareous subsoil.

11.4.5 Characterization

The science of characterizing soils, especially mineral soils has been fairly well established. The sampling density, techniques, accuracy, and the measurements of soil properties required for standard accuracy, and the measurements of soil properties required for standard soil surveys has also been defined. The application of standard soil

surveys to agriculture, either directly or through agriculture land capability systems, has been undertaken (see Section 4.6). The specific application of characterizing spoil for reclamation suitability has unique problems which render invalid the use of standard procedures as in the soil survey.

These problems can be differentiated into three related areas: (1) the soil sampling design, including the sampling in time, space, and depth continuums to obtain true representation of the actual population; (2) the choice and accuracy of properties to be measured and their relevance to reclamation success, and (3) the analytical techniques for obtaining valid estimates of these properties.

11.4.6 Sampling Design

Both spoils and soils are affected by cyclical seasonal variations which can be relatively easily accommodated in most sampling designs. Spoils and soils, however, differ markedly in their long-term stability and temporal variation. While soils tend to have reached a quasi-equilibrium with their environment over many thousands of years of pedogenesis, spoils are of recent origin and tend to exhibit marked changes over decades, as discussed in Chapter 13. Some prediction of the direction and magnitude of pedogenic changes of the spoil should be made in order to increase the long-term validity of reclamation plans. Some estimates of the effects of the initial leaching phase of the first five to ten years (see Chapter 5.3.5) can be obtained using various laboratory and incubation techniques (Grube et al. 1973) to determine nutrient release from the spoil (Berg 1978) and the susceptibility of the spoil to weathering (Grube et al. 1973).

Many authors reported marked spatial variability of spoil. Where this variation is known or can be easily obtained, it should be utilized to calculate a statistically significant sampling density (Berg 1978; Chadwick 1973; Grube et al. 1973; May et al. 1973). As an example of this variability, May et al. (1973) reported that in West

Virginia mine spoils over kaolin clay, pHs ranged from 4.0 to 7.9, extractable Ca from trace to 3600 ppm, and available P from 1 to 160 ppm. Reported sampling density recommendations may vary from 4 to 20 samples/ha (Berg 1978). Composite samples obscure the variability of spoil characteristics. Materials which appear physically different should be sampled separately. Predictions of average crop growth on spoil may be made more reliable by correlation with spatial variability of macro- and micro- nutrient levels (Chadwick 1973) and with pH (Berg 1978).

11.4.7 Analysis Techniques

Spoil texture presents problems both for sampling, analysis, and storage as it is often unstable once sampled (Berg 1978). Most spoils tend to be very coarse textured with a large proportion being >2 mm in diameter. This coarse fraction can represent a significant nutrient or toxicity source if porous and weatherable (e.g., shale). However, the coarse fraction in soil is usually relatively inert and can be excluded from chemical analysis. In spoil, there is no logical point at which to exclude cobbles or rocks, yet many analytical techniques are designed for very small masses of soil sample. Grinding to reduce the grain size increases surface area and material released (Berg 1978). Shaking, sieving, and ultrasonic dispersion techniques can also decrease the coarseness of the texture (Berg 1978; Grube et al. 1973). Standard gravimetric and neutron probe techniques are generally used for spoil moisture measurement, although little work has been done to test the validity of such techniques. Despite these problems, standard soil procedures are often used for spoil physical measurements and may result in significant error.

Analytical determinations of total elemental levels are fairly straightforward. For example, Sandoval and Power (1977) described detailed methods for many of these, including organic carbon, N, Ca, Mg, Na, K, and B. Some specific problems arise in differentiating mineral and organic forms of carbon, for example in the determination of coal or oil content in spoils. Down (1973) described a technique for estimating coal content of spoils. Basically, he used combustion (1100 to 1200°C for 24 h), of oven dry samples (50°C to constant weight) and corrected for organic matter and rock oxidation losses using the following formula:

$$\% \text{ coal in sample} = \frac{100}{WLc} (\%WLs - \%WLr - \%OM)$$

where: WLc is the weight loss of pure coal
WLs is the weight loss of the sample
WLr is the weight loss of the rock
OM is the weight of the organic matter

Techniques for determining oil content in soil mixtures, which could be applied to tailings sand or reclamation of oil spills, have been developed for land treatment of oily waste (Toogood 1977; Concawe Secretariate 1972).

The most complex analytical problems for spoils are determining plant-available nutrient levels and secondly plant-sensitive chemical imbalances in the spoil. The latter for example, would include acidity, alkalinity, salinity, and specific elemental toxicities. These two types of problems are discussed in turn.

Spoil texture problems and the unstable nature of most spoils make plant-available levels much more difficult to determine than total constituent levels. For example, it is extremely difficult to obtain unsaturated pastes, and extract sufficient soil solution from sodic spoils. Also, oxidation/reduction reactions of unstable spoil during

long extractions can markedly alter the levels of ions in the solution extract. In light of these problems, many authors recommend leaching, incubation (Berg 1978) or bioassay techniques (Chadwick 1973) in lieu of direct spoil testing.

Some specific analytical problems with N and P analysis have been identified. Berg (1978) and Grube et al. (1973) recommended $NaNO_3$ extraction for measuring available P as the acid Bray extraction is unreliable in neutral and alkaline spoil. Spoil N levels are equally difficult to characterize, especially the availability of N to plants. Since naturally present N in spoil may range from 10 ppm to 8000 ppm (Berg 1978), it cannot be assumed that most N accumulation occurs after disturbance and revegetation. Furthermore, N mineralization rates in exposed sedimentary rocks are much slower than in soils. Since inorganic N is usually low in spoils, incubation methods provide the most meaningful determination of plant available N.

The second major analytical problem--the measurement of chemical imbalances--is complicated by interaction and co-variation between properties measured, and the need to relate such measurements to plant stress. Berg (1978) discussed the problems in spoil measurements of pH, lime requirement, EC, and SAR. He suggested that pH should be measured in a salt solution such as 0.01M $CaCl_2$, to minimize the suspension effect and with the glass electrode immersed in the sediment. He also indicated that the common lime requirement test often underestimates requirements in sulfide rich spoils. Further, for materials with extreme pH values (< 4 or >10), EC measurement overestimates salt content (Berg 1978). Little information is presently available on the relationship between EC and plant growth. Although it is assumed SAR is a measure of Na toxicity, Berg indicated that it is not always correlated with Na or exchangeable sodium percentage (ESP). In contrast to macronutrient problems which are usually deficiencies, the major trace element problems in spoils have been toxicities, yet soil tests for B, Mo, Zn, Cu, Mn, and Fe have been designed to detect deficiencies (Berg 1978).

Despite these problems, many researchers still use traditional soil techniques. Sandoval and Power (1977) for example, described traditional detailed chemical methods for most macro- and micro-nutrients and fertility properties including pH, exchangeable cations, CEC, ESP, EC, NO_3, NH_4, NO_2, soluble P, and SO_4. These very closely reflect standard USDA soil survey methods with little or no modifications.

Thus, the spatial heterogeneity, the intense pedogenesis which causes marked temporal variation, and the coarse unstable texture of many spoils make their characterization difficult. Adequate sampling and analysis systems can develop only in response to specific research addressing these problems.

11.5 SUMMARY

Mine spoils have chemical properties that are often quite different from undisturbed soils, are difficult to measure, and that change relatively quickly with time. Spoils rarely provide as hospitable an environment for plant growth as do undisturbed soils.

Cation exchange capacity provides a useful index for predicting chemical requirements of spoil, both in terms of plant nutrient requirements and treatment of problems such as salinity or toxicities.

Spoil pH varies widely and often changes very quickly with time. The pH may initially decrease and then increase over a longer time. The pH of western spoils in general range from 2 to 12.

Plant nutrient status is perceived as a major reclamation problem, yet examination of fertility studies indicates that it is not being addressed in an analytical manner. Oil sands tailings are very deficient in macro- and micro-nutrients. Finer textured spoils, for example in plains regions, are more deficient in macro elements. Spoils may deteriorate, in terms of macro-nutrients, with age. Generally, Alberta spoils have limited toxicity problems.

Care must be taken in applying amendments to spoils. Nutrient interactions that may not be favourable result from antagonistic and

synergistic effects of elements. Macronutrients may be made unavailable or micronutrients may reach toxic levels.

Pedogenetic effects on spoil nutrients have not been well documented in Alberta. Trends found in studies from other ares indicate that this is a subject worthy of research.

Spoil acidity is not a problem in Alberta. In plains regions, spoils are more often alkaline and specifically the problem is sodicity/alkalinity. Saline spoils form less water stable aggregates and are subject to puddling. Water availability is limited and plant toxicities and nutrient imbalances occur. Groundwater use may be limited.

When sodium comprises 50% of soluble cations, soil becomes sodic. Such soils are subject to puddling, deflocculation, crusting, and cracking. Hydraulic conductivity is low and NO_3 formation is limited.

A large body of information on sodicity, salinity and alkalinity is available outside the reclamation literature. The reader is encouraged to consult such publications.

Conventional methodology for characterizing soils may not be appropriate for spoils. Spoils change in a relatively short time and prediction of the magnitude and direction of change is required. Spatial variability is also great. Sampling design should take such variability into consideration.

Spoil analyses is a major problem, generally centering around plant available nutrients and chemical imbalances. Research is required to determine whether standard methods are valid or if new methods are required.

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12. SOIL BIOLOGY

12.1 GENERAL SOIL MICROBIOTA

Parkinson (1978) presented an overview of existing knowledge of micro-organisms in restoring soil productivity. He pointed out that productivity of undisturbed terrestrial ecosystems has led to some understanding of the different components of ecosystems. One important interaction concerns the roles of microflora and fauna in organic matter decomposition and nutrient cycling in soil. The great importance of soil ecosystems has been recognized comparatively recently. Soil biological activities are very complex. Soil disturbance may drastically alter or reduce the abundance, species diversity, and activity of the organisms that inhabit the soil.

Parkinson discussed interactions between microbes and higher plants, which range from specific symbiosis such as occurs with root nodules and mycorrhizae, to free-living microbial forms. The effect of micro-organisms on higher plant growth is most pronounced, beneficially or harmfully, at the soil-root interface.

He also discussed the roles of microbiology in maintaining the balance between nutrient status and microflora. Reclamation of oil contaminated soil was one example used for illustration. Sufficient elemental nutrients are needed for repid decomposition of oil in soil. Thus fertilization of oil spills is usually appropriate. Conversely, inoculating oil contaminated soil with bacteria cultures to accelerate decomposition is usually not necessary and may, under certain conditions, cause environmental hazards. For instance Thiobacillus spp. produce sulfuric acid in pyritic coal spoils. In sewage amended spoil its presence may result in anaerobiosis and hydrogen sulfide evolution. All of these effects pose potential environmental problems.

Parkinson concluded that more research is required on restoring the general microflora in disturbed land, and understanding the way in which nutrient requirements interact with the microflora.

Cundell (1977) reviewed the biological processes involved in development of soil and the associated climax vegetation with special reference to strip mine or spent oil shale waste in North Dakota and Colorado. As soil evolves, the macro- and microflora of the soil play important and increasingly complex roles. Mosses and lichens are important in the early stages of soil formation. The soil microflora increase in numbers and complexity as organic matter accumulates and the soil C:N ratio declines. Symbiotic, associated symbiotic, and free-living nitrogen fixing bacteria, along with fungal mycorrhizae increase the supply of nitrogen and phosphorus for higher plants. Sulfur-oxidizing bacteria may have an acidifying effect which can be beneficial to sodic soils.

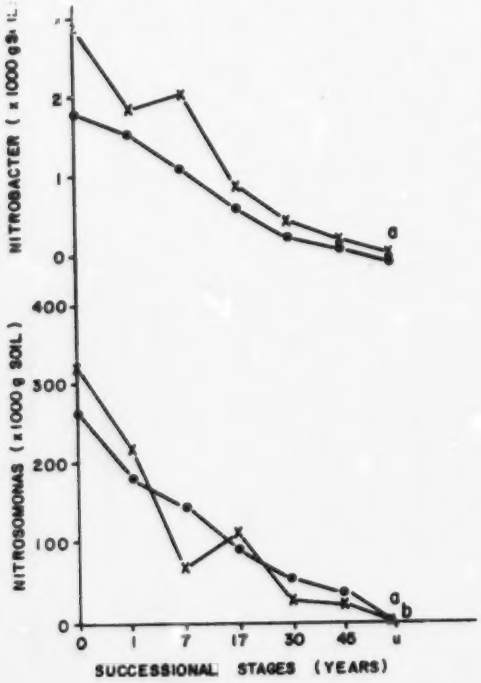
12.1.1 Bacteria

Lodhi (1979) studied changes in numbers of nitrifying bacteria and amounts of ammonium and nitrate nitrogen present in coal spoils of varying ages near Velva, North Dakota. Spoils were classified as 0 (newly deposited), 1 to 3, 7 to 9, 17 to 19, 30 to 32, and 45 to 47 years old. An unmined site was chosen to represent a climax ecosystem.

Nitrifying bacteria (Nitrosomonas spp. and Nitrobacter spp.) decreased in number from fresh spoil to the unmined spoils (Figure 12.1). As seen in Figure 12.2, the quantities of NH_4^+ were lowest in the early successional and increased to the climax stage. The nitrate levels were inversely related to ammonium levels.

From these data, the author noted that the gradual increase in ammonium and decrease in nitrate, Nitrosomonas and Nitrobacter numbers indicated that the developing ecosystem played an important part in the inhibition of nitrification. Lodhi stated that this agreed with results of other studies and may be due to the presence of polyphenols, tannins, and flavenoids found in climax vegetation communities.

In Yorkshire, England, Williams (1975) investigated the nitrogen cycle in two spoil heaps, one where the spoil pH was near



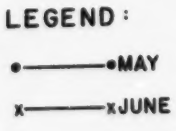


Figure 12.1 Effect of spoil age on numbers of soil nitrifying bacteria. Spoils are from various coal mines in the Velva, North Dakota area. U = unmined.

Source: Lodhi (1979).

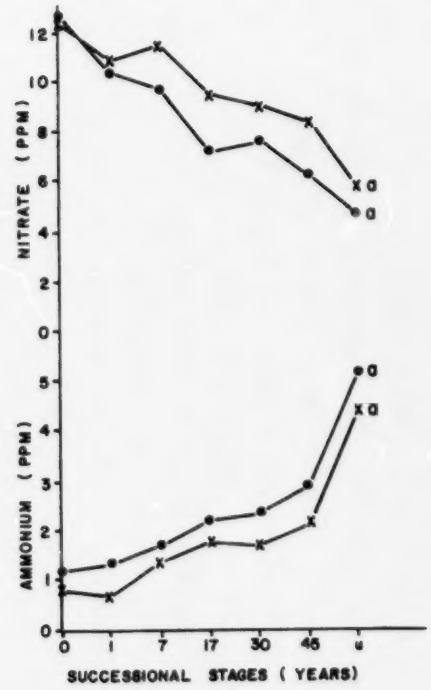


Figure 12.2 Effect of spoil age on soil ammonium and nitrate levels. Spoils are from various coal mines in the Velva, North Dakota area. U = unmined.

Source: Lodhi (1979).

neutrality (6 to 7) and one where spoil pH was acidic (3 to 4). Plot treatments included a control, shoddy at 3.6 t/ac, sewage sludge at 18.1 t/ac, and limestone at 7.2 t/ac. Vegetation on the plots was analysed for nitrogen content. Ammonium and nitrate production was determined in the laboratory on soil samples from the plots with added ammonium sulphate and calcium carbonate, singly or combined.

In the acid spoil, nitrification was inhibited. On the neutral soils, a large population of nitrifying bacteria rapidly converted ammonium to nitrate, so that most of the N taken up by plants would be as NO_3 rather than NH_4. The plot data showed that little or no N was available from the colliery spoil. Nitrogen supplied by rain or by wind-borne debris supported the vegetation of these spoils. Nonetheless, the investigation showed that a nitrogen cycle had become established on the near neutral spoil. On the acid spoil, available nitrogen was high but factors other than nitrogen were likely to be limiting for plant growth. At both sites nitrogen deficiencies were slowly remedied by natural processes.

Nordmeyer (1978) studied the effects of soil development and plants on the broad groups of bacteria in mountain soils in New Zealand. Bacterial numbers at 0.5 to 1 million/g were surprisingly high in sand and scree from high altitudes (Table 12.1). Bacteria numbers in grassland and forest plant litters were high at 100 to 150 million/g and, as expected, decreased exponentially with depth in the soils studied until, at about 1 m soil depth, the numbers approximated those in the scree. As the degree of soil profile development or pedogenesis increased, the total bacteria count increased, reaching a maximum in two older, more developed profiles (Table 12.2).

In these sites, Nordmeyer found that the pleomorphic group of soil bacteria, probably dominated by Arthrobacter spp., existed in screes in a fairly inactive state, and proliferated on those seasonal occasions when wind-borne dust and leaves were deposited as an energy source. On the other hand, the Gram-negative rods were clearly preferentially favoured in the root zone (below litter (L) layer), and

Table 12.1. Numbers of bacteria from a variety of alpine soils and unconsolidated natural materials in the Broken River Basin of New Zealand.

Soil	Material	Altitude (m)	Vegetation	Soil depth (cm)	Bacterial numbers in oven dry soil ($X 10^3$) /g
	Rock sand	1800	None	Surface	800
	Rock crevice	1800	None	Rock surface	450
	Rock crevice	1800	Colobanthus	Surface	24 000
	Rock crevice	1800	Moss	Surface	7 600
	Scree	1700	None	0 to 5	9 000
	Scree	1700	None	5 to 10	140
Spenser	Relict Grassland soil	1700	Chionochloa pallens	90 to 100	8 800
"	R. Grassland soil	1700	C. pallens	110 to 120	1 500
Kaikoura	Grassland soil	1560	Chionochloa macra	Litter	90 000
"	Grassland soil	1560	C. macra	5 to 10	38 000
"	Grassland soil	1560	C. macra	15 to 20	2 800
"	Grassland soil	1560	C. macra	40 to 45	2 400
"	Grassland soil	1560	C. macra	70 to 75	460
"	Grassland soil	1560	Celmisia lyallii	Litter	150 000
"	Grassland soil	1560	C. lyallii	5 to 10	42 000
"	Grassland soil	1560	C. lyallii	10 to 15	1 600
Bealey	Forest soil	1200	Nothofagus solandri	Litter	116 000
"	Forest soil	1200	var. cliffortioides	5 to 10	178 000
"	Forest soil	1200	N. solandri var. cliffortioides	40 to 45	3 600

Source: Nordmeyer (1978)

Table 12.2. Comparison of bacterial isolates from alpine scree, beech soil and snowgrass soil, from the Broken River Basin in New Zealand, on a weight (no. x 10^3/g O.D. soil) and volume (no. x 10^3/cc) basis.

Soil	Total bacteria		No. of Morphological Types						Carbon	Nitrogen
			Gm-neg. rods		Pleomorphic rods		Sp-forming rods			
	Per g	Per cc	Per g	Per cc	Per g	Per cc	Per g	Per cc	%	%
Scree	950	1 900	228	456	684	1 368	38	76	0.25	0.025
Beech soil L	33 000	4 290	20 790	2 703	11 880	1 544	330	43	42.95	0.77
Bealey F	62 000	13 640	53 950	11 867	8 060	1 773	0	0	31.9	0.88
Bealey H	4 300	2 084	2 236	1 053	1 720	825	334	165	7.8	0.33
Bealey subsoil	1 400	1 120	896	717	392	314	112	90	4.38	0.16
Snowgrass topsoil	25 710	11 312	20 054	8 824	2 824	1 244	2 828	1 244	10.54	0.36

Source: Nordmeyer (1978)

possibly relied largely on root exudates for their source of energy and protein (Table 12.3).

Soil fertilization with superphosphate and lime increased bacteria numbers under legumes 4 to 20 times (Table 12.4).

Nordmeyer (1978:71) concluded that at the present state of the science there is not enough knowledge of microbial activity to predict microbial population dynamics and microbial-soil organic matter interactions though three situations can be hypothesized.

1. "Under an intact forest or grassland the topsoil is dominated by roots. There is probably little soil that is strictly 'non-rhizosphere'. The conditions favour high numbers of bacteria, with a predominance of Gram-negative rods. Yet in spite of these very high numbers, there is no evidence that these soils are mineralizing nitrogen at a high rate. It is more likely that there is intense competition for any available nitrogen, phosphorus, and sulphur, and the removal of these nutrients by the plants may, in itself, depress the rate of mineralization through the loss of nutrients necessary for the further activity of the microflora.
2. "When the forest or grassland cover is removed by a fire, the immediate losses involve carbon, and some nitrogen and sulphur. Since the effect of living plant roots is removed, the bacterial population in the topsoil probably swings away from being dominated by Gram-negative rods, towards one dominated by pleomorphic rods. The soil is also subjected to some intense drying and wetting cycles and to greater fluctuations in temperature. All these processes probably favour increased rates of organic matter mineralization. It is possible that, at this stage, the process of nitrification (the bacterial conversion of ammonium-N to nitrate-N) becomes important. Since roots are not present to take up firstly the ammonium or secondly the

Table 12.3. Total numbers and morphological groups of bacteria isolated from alpine soil successions in the Upper Waimakariri Catchment Basin of New Zealand.

	Sample	Agar	Proportion of Morphological Groups (%)			Total $_3$count ($\times 10^3$/g soil)	Total $_3$count ($\times 10^3$/cc soil)	Number of Morphological types $\times 10^3$					
			Gm. neg. rods	Pleomorphic bacteria	Spore-forming rods			Gm. neg. rods		Pleo. rods		Sp. forming rods	
								/g	/cc	/g	/cc	/g	/cc
Waimak	2A[d]	N.A.[a]	25	73	2	1 397	2 430	349	607	1 020	1 774	28	49
"	2A	S.E.[b]	13	86	1	8 000	13 920	1 040	1 809	6 880	11 970	80	139
"	2D	N.A.	50	41	0	1 937	2 867	1 123	1 662	814	1 205	0	0
"	2D	S.E.	46	51	3	2 870	4 248	1 320	1 954	1 349	2 167	86	127
"	2E	N.A.	39	58	3	10 530	10 530	4 107	4 107	6 107	6 107	116	116
"	2E	S.E.	82	17	1	13 330	13 330	10 931	10 931	2 266	2 266	133	133
Waimak	4A	N.A.	10	90	0	900	1 737	90	104	810	1 563	0	0
"	4A	S.E.	19	68	13	1 500	2 896	285	550	1 200	2 316	15	30
"	4D	N.A.	55	38	7	6 000	5 821	3 300	3 200	2 280	2 212	420	409
"	4D	S.E.	50	46	6	4 500	4 365	2 250	2 183	2 070	2 008	180	174
"	4E	N.A.	75	25	0	23 100	13 870	17 325	10 400	5 775	3 465	0	0
"	4E	S.E.	84	15	1	37 000	22 200	32 080	18 650	5 520	3 331	370	219
Arthurs	4A	S.E.	19	75	6	3 770	(1)[c]	716		2 828		226	
"	4B	S.E.	48	54	6	4 670	(1)	1 868		2 522		280	
"	4C	S.E.	58	37	0	15 000	(1)	8 700		6 300		0	
"	4C	S.E.	66	17	3	17 000	(1)	11 220		5 270		510	
Arthurs	5A	S.E.	15	74	11	478		72		353		53	
"	5B	S.E.	6	90	4								
Arthurs	6	S.E.	50	36	11	24 000		12 000		9 360		2 640	

Source: Nordmeyer (1978)

a N.A. = nutrient agar.

b S.E. = soil extract agar.

c (1) = Volume weights not available.

d 2E, 4C, 4E are organic horizons. All others are scree.

Table 12.4. Bacteria in phosphate fertilized and limed alpine soil plots collected from the Craigieburn range of New Zealand, and sown with introduced legumes.

Legume	Fertilizer	Number Total bacteria x 10^3/g	Proportion of morphological groups %			No.of morphological groups x 10^3/g		
			Gram-neg rods	Pleomorphic rods	Spore-forming rods	Gram-neg rods	Pleomorphic rods	Spore-forming rods
Control vegetation	0	139	0	56	44	0	78	61
White clover	Super	525	24	62	14	126	326	73
White clover	Super + Lime	1 780	13	85	2	231	1 513	36
Alsike	Super	2 640	44	52	4	1 161	1 373	106
Alsike	Super + Lime	2 025	64	36	0	1 296	729	0
Red clover	Super	1 195	7	86	7	84	1 028	83
Red clover	Super + Lime	1 600	20	78	2	320	1 248	32
Average vegetated soils		1 627				536	1 036	55

Source: Nordmeyer (1978)

nitrate, this is the stage where loss of plant nutrients can be greatest. In the long term, most of the soil's organic matter is lost by erosion, and increased mineralization is followed by subsequent leaching of nutrients.

3. "When revegetation is attempted on an eroded soil, or under natural plant succession, there will be an early phase, possibly existing for many years, where cover is incomplete. Again, there will be fluctuations in temperature and moisture which will favour mineralization of the organic matter that is being deposited by plants. When rooting mass increases, the population of bacteria should shift towards the Gram-negative rods and mineralization rates/unit of added organic matter would fall.

"The practical implication of this is that to get rapid organic matter accumulation on a scree surface, the requirements would be:

1. Nitrogen-fixing plants with supplies of phosphorus and sulphur;
2. A rapid development of rooting density to tie up the mineralized nutrients derived from litter; and
3. A rapid development of canopy to even out temperature fluctuations.

"About the time of canopy closure, root density and the demand for nitrogen will be increasing as the plants develop more of a 'sink' to tie up available nitrogen. It is possible that the revegetation plants will begin to show symptoms of nitrogen stress at this stage."

Nordmeyer (1978) pointed out that many high altitude soils contain 4000 to 6000 kg/ha of N in the organic matter. The source of such N is unknown since nitrogen fixing plants are uncommon at such altitudes. His attempts to isolate and count free-living N-fixing

bacteria indicated that they were not a significant source as Beijerinckia sp. was the only free-living N-fixer isolated and in number it did not exceed 10/g of dry soil. In established plant communities, such bacteria could make small contributions to the pool of soil nitrogen.

Further experiments suggested fertilizer and lime can enhance Rhizobium spp. numbers. However, it is not yet clear whether it is Ca, PO_4, N, or pH which is more important in the rhizobia proliferation (Tables 12.5 to 12.7).

Initial results also suggested that "clover rhizobia" can increase considerably in soils or on root surfaces over time (Table 12.8).

12.1.2 Mycorrhizae

It is well known that trees tend to be infected by ectomycorrhizae fungi whereas herbaceous plants, especially grasses, tend to be infected with endomycorrhizae (e.g., Marx 1975). Since spoils are usually infertile growth mediums, some fungi and bacteria or actinorhizal symbiosis is usually necessary to supply plant nutrient requirements. Thus when revegetating spoils, inoculum must be introduced either naturally or artificially to ensure plant establishment and survival.

Fessenden (1979) reported that of the many species tested for reclamation almost all those in common use are actinorhizal. It is commonly assumed or inferred that nodulated plants (i.e., with bacterial or actinorhizal symbiosis) are also mycorrhizal. It is also well known that the nodulation enhances plant N uptake and fixation primarily from the soil gases and within living plant tissues and in addition that mycorrhizae enhance P and Zn uptake primarily from the soil solution. High levels of plant available N and P in the soil inhibit the development of these symbiotic relationships (e.g., Trappe 1979). Trappe also suggests mycorrhizal fungi seem to absorb minerals and nutrients from the soil and translocate them to the host plants and to the nodule endophytes or bacterial and actinorhizal symbionts.

Table 12.5. Numbers of *Rhizobium trifolii* in fertilized subsoils from New Zealand alpine soils in the presence and absence of white clover.

Fertilizer (kg/ha)	pH	No. of rhizobia x 10^{-3}/g o.d. soil			
		14 days		21 days	
		- Clover	+ Clover	- Clover	+ Clover
0	4.9	5	7	7	75
P40	5.0	74	750	500	2300
P100	5.1	74	5500	5500	5500
P40 L2000	6.8	5	7500	5500	2100
P100 L2000	6.8	750	5500	750	7500
P100 L2000 K20	6.8	470	5500	4600	7500

Source: Nordmeyer (1978).

Table 12.6. Numbers of *Rhizobium trifolii* in a lime or phosphate amended alpine subsoil from New Zealand.

Treatment (kg/ha)			
Lime	Phosphorus	pH	No. of rhizobia x 10^{-6}/g soil
0	0	5.0	16
0	200	5.2	298
1000	0	7.1	731
1000	200	7.0	733
2000	0	7.4	853
2000	200	7.4	691

Source: Nordmeyer (1978).

Table 12.7. Numbers of Rhizobium trifolii in a nitrogen amended alpine subsoil from New Zealand.

Nitrogen added (kg/ha)		pH	No. of rhizobia x 10^{-6}/g soil
--	0	5.0	16
Urea	10	5.0	29
Urea	40	5.1	407
NH_4Cl	40	4.3	17
$NaNO_3$	40	4.6	25
Dried blood	40	5.1	35

Source: Adapted from Nordmeyer (1978).

Table 12.8. Numbers of Rhizobium in some alpine New Zealand soils under commercial Lotus pedunculatus and Trifolium repens after eight year's growth.

Species sown	Lime (kg/ha)	No. of rhizobia x 10^{-3}/g soil	
		Lotus rhizobia	White clover rhizobia
Clover	2000	1.5	24 000
Lotus	2000	462	1 099
Lotus	0	43	0.9

Source: Nordmeyer (1978).

Unpublished research by Parkinson (University of Calgary, personal communication) indicates mycorrhizal status of many spoils is very low and slow to recover by natural inoculation after revegetation. Little is known about the status of bacterial and actinorhizal symbionts in spoil; however, the preceeding discussion would suggest low mycorrhizal levels would inhibit the development of bacterial and actinorhizal nodulation. Beyond this very little information is available on interaction between mycorrhizal, bacterial, and actinorhizal plant symbiosis (Trappe 1979).

Marx (1976) provided an excellent description of root-inhabiting fungi, describing these as being the most widespread symbiosis of plants involving root-inhabiting fungi and plant feeder roots. There are three classes of these fungi:

1. Ectomycorrhizae which grow vegetatively over the feeder root surface to develop hyphae intercellularly in the root and to radiate hyphae to the base of fruiting bodies. Dissemination of the fruiting bodies is by wind and water.
2. Endomycorrhizae which do not produce large above-ground fruiting bodies. They also do not develop a dense hyphal mantle about the roots but penetrate into the cortical cells where specialized absorbing or nutrient exchange structures, called arbuscules, are formed. Dissemination of fruiting bodies is by root contact, moving water, insects or animals.
3. Ectendomycorrhizae which have features of both the ecto- and endomycorrhizae but are of minor occurrence.

The occurrence of fungal endophytes in the roots of the major groups of plants that colonize coal mine spoils in Pennsylvania and Scotland was surveyed by Daft, Hacskaylo and Nicholson (1975) and Daft and Nicholson (1974). The former surveyed three coal spoils in Scotland for the presence of vesicular-arbuscular (VA) mycorrhizae. The spoils varied significantly in pH, P level, and degree of colonization, eight to ten years after the last active spoil addition.

Spoil pH, total P, and extractable P varied from 4.3 to 7.4, 675 to 1087 ppm and 0.35 to 2.3 ppm, respectively.

On all three spoils Endogone spp. was the most common mycorrhizae found. A more detailed survey of the Devon spoil was made (Table 12.9) and the presence of E. fascicula and E. calospora was indicated. Attempts to identify an endophyte of unknown affinity with narrow hyphae were unsuccessful, as were attempts to relate the rate of root hair production with the rate of mycorrhizal infection.

Almost all species were infected with arbuscular mycorrhizae (Daft, Hacskaylo and Nicholson 1975). Mycorrhizal infection may be essential for the survival of most herbaceous plants on coal mine waste. The importance of endophyte infection for the growth of pioneer plants on coal tips may be based on stimulation of growth under low phosphate conditions. The response of a Zea mais hybrid, Fragaria vesca and Medicago sativa, taken from a Scotland coal mine tip to inoculation with a fungal endophyte was studied experimentally. Zea and Fragaria responded positively to mycorrhizal infection particularly after upward adjustment of soil pH (Table 12.10).

The authors reported a major contribution of the fungal endophyte to the legume host growth in increasing the efficiency of the nitrogen-fixing nodules although the data were not presented.

In Pennsylvania, Shuffstall and Medve (1979) compared growth parameters and mycorrhizal characteristics for 10 hardwood species which naturally invade bituminous spoil and four exotic hardwoods commonly used in local spoil reclamation. Although reclaimed coal spoils are typically hostile plant environments, the indigenous species of Sassafras sp., Acer rubra, Populus tremuloides, Crataegus rivularis, and Robinia pseudoacacia tended to grow better on coal spoils than on soils (Table 12.11). Mycorrhizal infection rates were very high for these species with the exception of R. pseudoacacia (Table 12.12).

The nitrogen fixing ability of R. pseudoacacia explains its independence from mycorrhizal infection. This indigenous species compared favourably or better to the exotic species for growth and mycorrhizal characteristics (Table 12.13).

Table 12.9. Mycorrhizas in grasses and herbaceous dicotyledons from the Devon, Scotland coal spoil[a] (sampled October 1972).

Host	Mean[b] mycorrhizal infection (%)	Endophyte
GRASSES		
Dactylis glomerata	38.2	*Endogone* sp. only
Festuca ovina	40.8	
Holcus lanatus	83.9	
H. lanatus	56.0	Narrow endophyte only
Agrostis tenuis	40.8	Mostly narrow endophyte but some *Endogone* sp.
Holcus lanatus	56.5	*Endogone* only
Festuca ovina	57.8	
DICOTYLEDONS		
Chamaenerion angustifolium	41.1	Mostly narrow endophyte with some *Endogone* sp.
Senecio viscosus	40.8	*Endogone* sp. predominantly but some narrow endophyte
Cirsium arvense	33.5	
Reseda luteola	0.0	--
Senecio viscosus	36.4	Narrow endophyte only
Chamaenerion angustifolium	58.5	Mostly narrow endophyte with some *Endogone* sp.
Rubus fruticosus agg.	20.0	Probably both endophytes
Chamaenerion angustifolium	23.1	*Endogone* only
Senecio viscosus	23.8	*Endogone* sp. predominating but some narrow endophyte
Fragaria vesca	62.5	*Endogone* sp. only

Source: Adapted from Daft and Nicholson (1974).

[a] Spoil pH = 4.6; total P = 675 ppm; extractable P = 2.3 ppm.

[b] Mean of six determinations.

Editor's Note: The *Endogone* genus has been revised (after 1974) to a complex of genera.

Table 12.10. Effect of mycorrhizal infection on the growth of Fragaria vesca collected from the Devon tip, grown in pots containing sterilized spoil material. Plants grown for 12 months and infected with Glomus macrocarpus var. geosporus (ex. coal spoil).

	Mean Fresh[a] weight (g)	Mean Number of Leaves	Mean Infection (%)
Control	1.73	5.4	17.6
Mycorrhizal	2.08[b]	7.3	82.1

Source: Daft, Hacskaylo and Nicholson (1975).

[a] Mean of 20-24 plants.

[b] Significant at 1% level.

Table 12.11. Comparative growth index of indigenous species on bituminous strip mine soil in Pennsylvania and non-strip mine soil.

Species	Comparative Growth Index[a]
Sassafras	148
Red maple	144
Quaking aspen	118
Hawthorn	106
Black locust	103
Flowering dogwood	95
Smooth sumac	88
Large tooth aspen	83
Black cherry	78
Hercules' club	70

Source: Adapted from Shuffstall and Medve (1979).

[a] Values: 100 indicate more growth on bituminous strip mine spoil than on non-strip mine sites.

Table 12.12. Type and percent mycorrhizal infection of indigenous species growing on strip mine spoil in Pennsylvania and non-strip mine soil.

Species	Area Collected	Type Mycorrhiza	% Mycorrhiza Infection
Red maple	Non-spoil	Endo.	89
	Spoil	Endo.	55
Hercules' club	Non-spoil	Endo.	50
	Spoil	Endo.	15
Flowering dogwood	Non-spoil	Endo.	84
	Spoil	Endo.	95
Hawthorn	Non-spoil	Endo.	25
	Spoil	Endo.	90
Large tooth aspen	Non-spoil	Ecto.	97
	Spoil	Ecto.	98
Quaking aspen	Non-spoil	Ecto.	86
	Spoil	Ecto.	95
Black cherry	Non-spoil	Endo.	26
	Spoil	Endo.	15
Smooth sumac	Non-spoil	Ecto.	56
	Spoil	Ecto.	70
Black locust	Non-spoil	Ecto.	10
	Spoil	Ecto.	11
Sassafras	Non-spoil	Endo.	90
	Spoil	Endo.	85

Source: Shuffstall and Medve (1979).

Table 12.13. Mean values for growth and mycorrhizal characteristics of exotic and indigenous species found on bituminous strip mine spoils.

Species	Type Mycorrhiza	Growth (mm)	% Mycorrhizae
European white birch	Ecto.	89	94
Hybrid poplar	Ecto.	196	65
Autumn olive	Endo.	296	27
European alder	Endo.	233	91
5 Ind. Sp.[a] with best growth characteristics		262	49

Source: Shuffstall and Medve (1979).
[a] 2 with endomycorrhiza, 3 with ectomycorrhiza.

Lindsey, Cress and Aldon (1977) studied in vitro the growth response of Chrysothamnus nauseosus, Atriplex canescens, and Zea mais on a north-western New Mexico coal spoil. Of the plants inoculated with Glomus fasciculatus and Glomus mosseae, only Chrysothamnus showed significant enhanced growth and survival response to G. fasciculatus (Table 12.14). The response was attributed to increased P uptake, and indicates infection was successful when spoil was low in P but contained adequate N and acceptable pH levels; in this case 0.52 ppm extractable P, 320 ppm NO_3, and pH 6.7.

In a similar study in New Mexico using Atriplex canescens and Chrysothamnus nauseosus, Aldon (1978) found these species survived and grew better when inoculated in the greenhouse with a known endomycorrhizal fungus and transplanted to the same coal spoil (Table 12.15). After two growing seasons, survival and growth were significantly better in plants grown on soil infected with a phycomycete (G. mosseae) reported to form endomycorrhizae on many plant species. Fourteen important shrub species were found to form endomycorrhizae under field conditions.

From experiments conducted on coal spoil in Illinois, Ponder (1979) also reported that endomycorrhizal infection was easily established in vitro. Endomycorrhizal fungi were evident after three weeks on Lolium sp., Sorghum sudanense, and Juglans nigra grown in the greenhouse on non-autoclaved spoil, compared with no infection on plants grown on autoclaved soil.

Reid and Grossnickle (1978) conducted a comprehensive study involving three mycorrhizal fungi used to inoculate three conifer species germinated and grown in the greenhouse and later transplanted to plots on a tailings pond in Colorado with a range of fertility treatments. Natural innoculation by indigenous fungi in the control treatment when compared to artificial innoculation with three test species produced equal or greater mycorrhizal establishment and growth gains for the trees (Table 12.16).

Marx (1975) in studies on coal spoils in Ohio, Virginia, and Kentucky found Pinus spp. inoculated with Pisolithus sp.

Table 12.14. Effect of endomycorrhizae on Chrysothamnus nauseosus grown on New Mexico coal spoil material for 132 days.

Treatment	Mycorrhizal Condition	Height cm	Dry Weight ug/g
Sterilized spoil material			
Control	-	1.2 a	11 a
Soil washings	-	1.9 a	20 a
Mycorrhizal inoculum	+	6.7 b	149 b
Non-sterilized spoil material			
Control	-	1.5 a	36 a
Soil washings	-	1.5 a	22 a
Mycorrhizal inoculum	+	5.5 b	127 b

Source: Adapted from Lindsey, Cress and Aldon (1977).
Note: Means in the same column followed by the same letter do not differ significantly at 1% level.

Table 12.15. Growth and survival in a New Mexico coal spoil of mycorrhizal and non-mycorrhizal infected Atriplex canescens plants.

	Mycorrhizal	Control
Height (cm)	41.7	27.4
Diameter (cm)	35.8	21.3
Size index (height x diameter, cm^2)	1493.0	584.0
Survival (%)	95.0	84.0

Source: Aldon (1978).

Table 12.16. Growth responses of containerized conifer seedlings with various mycorrhizal fungi inoculation.

Mycorrhizal[a] Species	Root Length cm	Top Length cm	Total Length cm	Root Dry Wt. g	Shoot Dry Wt. g	Total Dry Wt. g	% MYC[b]	Stem Diameter mm	R/S (DW)[c]	gH_2O/gDW
Pinis contorta										
P.t.	34.82	7.51	42.63	0.2565	0.3239	0.5804	78.1	1.45	0.8335	3.30
S.g.	33.04	11.22	44.27	0.5207	0.9053	1.425	78.7	2.18	0.5854	3.00
C.g.	29.85	7.79	37.64	0.280	0.441	0.6209	64.4	1.85	0.6480	2.87
Control	31.45	10.33	41.78	0.535	0.810	1.340	77.2	2.1	0.6908	2.59
Pinus flexilis										
P.T.	29.48	5.88	35.36	0.323	0.419	0.742	55.3	1.95	0.8783	3.27
S.g.	25.91	7.14	33.06	0.589	0.982	1.571	55.0	2.5	0.6506	2.62
C.g.	28.09	5.81	33.86	0.328	0.450	0.778	55.3	1.8	0.7405	3.09
Control	28.81	7.29	36.12	0.477	1.173	1.65	55.0	2.3	0.4269	2.43
Picea engelmannii										
P.t.	21.35	6.08	27.43	0.0936	0.1533	0.2469	1.5	1.1	0.5881	2.16
S.g.	24.96	10.39	35.35	0.2642	0.4844	0.7486	7.8	2.1	0.5712	2.45
C.g.	22.76	6.74	29.5	0.0795	0.1547	0.2342	5.5	1.35	0.4921	2.94
Control	26.7	11.09	35.59	0.4138	0.6183	1.1007	1.5	2.3	0.5998	2.13

Source: Reid and Grossnickle (1978)

[a] P.T. = Pisolithus tinctorius; S.g. = Suillus granulatus; C.g. = Cenococcum graniforme; Control = Inoculation by unknown fungus.

[b] % MYC represents the percentage of short roots which were mycorrhizal.

[c] R/S is root/shoot ratio based on dry weight.

ectomycorrhizae prior to outplanting established better than trees inoculated with other symbionts. Some trees such as Pinus spp. are in fact obligate symbionts, requiring infection with fungi for normal growth. Little research on endomycorrhizal infection of trees has been undertaken although preliminary studies indicate symbionts can enhance P uptake. The main factors influencing or enhancing infection appear to be high photosynthetic potential (bright sunlight) and limited fertility. Marx also reviewed reported species specific fungi commonly found in spoils and their preferred host tree species. For example, few ectomycorrhizal fungi are capable of adapting to anthracite spoil. Also, Pisolithus more than other ectomycorrhizal fungi may enhance Pinus and Betula species growth on spoils.

In addition to trees, the performance of grasses and other herbaceous plants used in revegetation may be improved by infection with specific endomycorrhizal fungi. Endogone gigantea is one of many endomycorrhizal fungi which can enhance herbaceous plant growth on coal spoils.

In the Kentucky studies, Pinus virginiana and P. resinosa seedlings were grown for five months in a growth room in soil infected with two species of ectomycorrhizae. They were then transplanted onto coal mine spoil in an experiment that also included conventional nursery-grown seedlings. Roots of half of these seedlings were dusted with dry basidiospores of ectomycorrhizal fungi. Although the seedlings were not dormant at the time of transplanting and may have been killed by late spring frost, the ectomycorrhizal infection increased survival and growth of the trees (Table 12.17).

The other experiments reported by Marx gave similar results. Thus Marx's conclusion was that manipulation of mycorrhizal fungi on tree roots has great potential in reclamation of drastically disturbed land as well as in conventional reforestation.

12.1.3 Earthworms, Arthropods, and Vertebrates

The activities of macro-animals have an important bearing on the development and properties of soils. The beneficial effect of the

Table 12.17. Survival and growth of Virginia and red pine seedlings with different ectomycorrhizae after two years on a coal spoil in Laurel County, Kentucky.[a]

Pine Species	Ectomycorrhizal condition at planting	Percent Survival	Height (cm)	Stem Dia. (cm)	(Stem dia)[b] x height (volume)	Percent Pisolithus[b]
Virginia[c]	Pisolithus	28[e]	37.8[e]	1.14[e]	49.1[e]	70[e]
	Thelephora	15	18.1	0.72	9.4	8
Red[c]	Pisolithus	22[e]	8.5	0.43	1.6	82[e]
	Thelephora	7	7.0	0.41	1.2	10
Virginia[d]	SNS + spores	25	41.2	1.30	69.6[e]	85[e]
	SNS	32	37.6	1.14	49.9	40
Red[d]	SNS + spores	55[e]	18.1	0.74	9.9[e]	65[e]
	SNS	40	17.3	0.57	5.6	15

Source: Adapted from Marx (1976).

[a] Spoil analysis were pH 3.0, 0.14% total N, 0.05% total S, and 2.7% organic matter, with 14.6, 53.8, 423.4, 127.7 and 32.5 kg/ha of P, K, Ca, Mg and NO_3, respectively.

[b] Percent of surviving seedlings with Pisolithus ectomycorrhizae after two years on site.

[c] Seedlings grown in Athens growth room for five months. Due to lack of dormancy at planting many seedlings died following late frosts.

[d] Standard nursery stock seedlings with or without Pisolithus spore dust on roots at planting.

[e] Denote significant differences (P = .05) between Pisolithus and Thelephora and SNS vs. SNS + spores on a pine species.

mixing action of burrowing animals on the surface horizons of soils has long been recognized. Earthworms incorporate raw organic residues into the soil by shredding or grinding which also facilitates its decomposition by soil microflora.

Vimmerstedt and Finney (1973) conducted a series of experiments to determine whether earthworms could be established on spoil banks soon after revegetation and to determine their effect on soil formation. On calcareous coal mine spoils in Ohio, plots 0.6 m^2 were isolated by fibre-glass screening. Earthworms (Lumbricus terrestris) were released on the plots and five years later the numbers of worms, depth of tunnels, and other activities were measured. In a second study the spread of an earthworm population, begun by releasing 10 worms (L. terrestris) on a calcareous spoil vegetated with Alnus glutinosa, was measured after five years. In a third study in the greenhouse, earthworm (L. terrestris) activity in consuming and mixing leaf litter was studied on a dark acid shale spoil.

The worms persisted for five years and buried or consumed 5 t of leaf litter per hectare. Exchangeable cations were increased but available P in the spoil decreased (Table 12.18). The results in vitro showed a decrease in available P with earthworm inoculation. The earthworm activity did not affect the growth of Quercus sp. seedlings subsequently grown on the soils in the greenhouse.

Spread of earthworms in five years reached 60 middens or colonies/m^2 (Table 12.19). Clearly, earthworms can be established on revegetated coal spoil banks where they promote incorporation of organic matter into the spoil.

In a comprehensive study of the invertebrate fauna of a coal pit heap in England, Hutson, Luff and Selman (1972) recorded the survival and growth of earthworms on soils and shales with and without a surface covering of grass clippings. The experiment was conducted in the laboratory. Worms did not survive on a grey, moderately saline shale with a low moisture equivalent. In the other cultures, the addition of grass caused a significant increase in the weight of worms. Worms would likely not survive in shale spoils during dry periods

Table 12.18. Nutrient status of Ohio spoil samples from field plots and cores with and without earthworms.

Samples	Total N %	Available P ppm	Exchangeable cations meq/100 g K	Ca	Mg	pH[a]
FIELD SAMPLES						
1969						
With worms	0.12	7.93[b]	0.28	1.97	1.65	
Without worms	0.11	12.03[b]	0.24	1.86	1.49	
1972						
With worms	0.13	4.97[b]	0.32	1.67	0.89	3.5
Without worms	0.11	6.37[b]	0.26	1.64	0.83	3.4
CORE SAMPLES						
With worms	0.06	4.25[b]	0.19[c]	2.72[c]	2.47[c]	
Without worms	0.08	1.74[c][sic]	0.17[c]	1.69[c]	1.79[c]	

Source: Vimmerstedt and Finney (1973).

[a] Measured at 0.01 M $CaCl_2$.

[b] Significantly different at P = 0.05 level.

[c] Significantly different at P = 0.01 level.

Table 12.19. Midden density, distance to nearest neighbour, and extent of departure from a random distribution for earthworms on calcareous Ohio spoils.

	Distance from Initial Point of Introduction (m) 0	5	10	15	20	25
Middens per square metre	59.0	62.0	64.0	54.0	29.0	16.0
Mean distance to nearest neighbour (cm)	8.5	7.5	7.9	8.2	9.5	16.1
R, ratio between observed mean distance and mean distance in random distribution of this density	1.3	1.2	1.2	1.2	1.0	1.3

Source: Vimmerstedt and Finney (1973).

because these spoils dry so rapidly. Packing of the shale below 10 to 15 cm by earthmoving equipment may also impede the burrowing of the worms when they attempt to avoid drought or freezing surface temperatures. Grass clippings left on the surface would, however, reduce evaporation and aid in the survival of soil organisms. In the experiment the worms pulled much of the organic residues into the soil.

Satchell and Stone (1972, 1977) studied earthworm activity and survival in pulverized fuel ash. Earthworms were kept in nylon bags of ash with a handful of leaf litter for food. The test was conducted outdoors and numbers and weights of worms were recorded at intervals. Natural colonization of ash sites in the field was assessed by using formaldehyde as an expellant at intervals along transects oriented toward suspected sources of colonization.

The results indicated that earthworms are unlikely to penetrate hard pans of cemented ash and are therefore unlikely to improve drainage where these occur. Fly ash is normally devoid of the necessary food supply and too saline to maintain a continuously regenerating earthworm population. Drainage problems in compacted wet clay may be helped by earthworm activity only if organic residues are present as a food supply. Topsoil can supply this food and will usually also contains an introduction of worms. The incorporation of organic residues into the surface horizons by the earthworms improves the nitrogen retention of fly ash. Where heavy clay is used as a surface amendment earthworm populations will be lower than where topsoil is used.

A survey of invertebrates in addition to earthworms, on a coal pit keep in England was conducted by Hutson, Luff and Selman (1972). Numbers extracted from soil samples or caught in pitfall traps were recorded. In the 17 months after earthmoving was completed and 11 months after the areas were sown, the sites were rapidly colonized. Most insect families found on the control area were also represented on the heap although the relative percentages differed. Topsoil or shale fields had similar numbers to a nearby pasture. Differences in numbers were realted to soil pH and salinity. Fluctuations in numbers with

time were correlated with weather, particularly the occurrence of drought which was accentuated by the porous nature of the shale.

Ettershank et al. (1978) discussed the abilities of termites (Reticulitermes tibialis) and other soil fauna to modify physical and chemical properties of coal mine spoils. Using spoils from the McKinley Mine, near Gallup, New Mexico, they observed changes in spoil following the introduction of termites from the surrounding undisturbed areas. They found that EC, Na, K, SO_4, NO_3, % organic matter, saturation %, and % silt and clay fractions decreased while Ca, Mg, HCO_3, Cl, PO_4, and % sand fraction increased in the spoils with termites.

In a second study the authors collected soil samples from three reclaimed areas and three undisturbed areas to determine the presence of microarthropods under various reclamation treatments. Mulching with bark or straw provided a more suitable habitat for microarthropod populations than the topsoiling treatment. This suggests that topsoiling, without the addition of an organic mulch, may not be sufficient to establish soil biota. The authors noted that presence of soil microarthropods is indicative of a maturing ecosystem and that they greatly affect rates of organic matter breakdown and mineralization.

12.2 SUMMARY

Soil disturbance may drastically alter or reduce abundance, species diversity, and activity of organisms. The study of effects of mining and subsequent reclamation practices on soil microbiota is relatively recent and incomplete. Some excellent research has been carried out in Alberta by Dr. Dennis Parkinson and his associates at the University of Calgary and is ongoing at the present time. Several reports will be available in the near future.

Symbiosis of plants and soil micro-organisms can be critical to reclamation success. However the present state of knowledge is probably not adequate to predict microbial population dynamics and microbial/soil organic matter interactions. Under native soil

conditions, high bacterial content is favoured with a predominance of Gram-negative rods. When soil is denuded and organic matter reduced, the population swings to a predominance of pleomorphic rods. Organic matter mineralization increases and, under denuded conditions, loss of nutrients can be great. As plants establish, the shift is back to Gram-negative rods and mineralization rates decrease.

Acidity and other chemical factors can severely reduce bacterial numbers and nitrogen cycling.

There appears to be considerable interaction between bacteria, actinorhizae and mycorrhizae symbiosis; however, very little information is available.

Mycorrhizal infection (natural or through innoculum) may very well be essential for the establishment of plants on spoils, particularly under low phosphate conditions. High levels of N and P may inhibit symbiotic relationships and result in the need for continued maintenance fertilization.

Plant/fungi relationships are often very species specific and some mycorrhizae are of very little value to survival and productivity of plants. Unproductive relationships may, however, be antagonistic to inoculation of more valuable fungal species.

Earthworms, arthropods and small vertebrates provide mixing, aeration, and incorporation of organic materials to soils. Introduction of these animals to new spoils has resulted in improved physical characteristics and increased rate of pedogenesis. Earthworms, and other invertebrates, can be inoculated into spoils with amendments, such as topsoil, that also supply necessary food supplies.

Drought, chemical characteristics, and physical characteristics (e.g., high bulk density) may impede successful colonization by earthworms and other invertebrates.

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SECTION IV

SPOIL DEVELOPMENT AND CLASSIFICATION

13. PEDOGENESIS

Natural soils in the temperate and cold climate of Alberta were formed over long periods of time by complex physical, chemical, and biological properties. With the exception of N where atmospheric fixation is an important source, most of the nutrients are released from the parent material by weathering in situ. Two main types of weathering are recognized. One is physical weathering, in which the original rock disintegrates to smaller-sized material, with no appreciable change in chemical or mineralogical composition. The other is chemical weathering, in which the chemical and/or mineralogical composition of the original rock and minerals is changed. In nature, physical and chemical weathering occur together, and it may be difficult to separate the effects of one from the effects of the other (Birkeland 1974:52).

Weathering, in this case, consists of the continual physical breakdown of large rock fragments and mineral grains into smaller ones, and the chemical alteration and solution of compounds in the parent material. Pedogenesis also includes translocation and deposition of materials and compounds, and complex alterations such as clay mineral formation and humification of organic matter. In natural soils pedogenesis eventually causes soil profiles to develop with lateral layers, termed horizons, of differing soil characteristics.

In spoil piles, weathering is the dominant initial pedogenetic process and lasts for many decades. In very old spoil piles, for example in the U.K. and eastern seaboard, there is evidence of other pedogenetic processes such as oxidation, humification, illuviation, and more profile development (Down 1975b; Smith, Tryon and Tyner 1971).

Pedogenesis of these spoils can improve their nutrient status and fertility (Caspall 1975; Grube et al. 1973) by increasing macro- and micronutrient levels, by organic matter accumulation and ameliorating acidity (Caspall 1975; Down 1975a,b), and, although undocumented, by increasing the uniformity and distribution of positive and negative fertility components. Pedogenesis, however, can also worsen the fertility status by increasing heavy metal levels (Como et al. 1978; Lavkulich et al. 1978; Struthers 1964), by releasing excessive salts or

Na, and by causing deterioration in soil structure (Down 1975b; see also Chapters 11.3.1, 11.3.2, and 11.4.4).

An understanding, then, of spoil pedogenesis is crucial to long term predictions of the stability of reconstructed soils and reclamation success.

Some short term studies of spoil pedogenesis in North America have been reported. Pedersen, Rogowski and Pennock (1978) reported minimal soil development in Pennsylvania mine spoils after 10 years. In this study the clay mineralogy of undisturbed soils and mine spoils indicated similar material origins; in general, however, mine spoils are less weathered than parent materials in natural or agricultural soils.

Struthers (1965) reported brown colour changes in the top few centimetres of spoil within 8 to 10 years of tree and forage crop establishment, thus suggesting initial pedogenesis. The protection of vegetative cover facilitates organic matter accumulation by minimizing surface erosion and by adding biomass to the litter layers (Caspall 1975). Although development of a mature soil profile normally takes in excess of 1000 years (Birkeland 1974), in temperate climates initial pedogenesis can be anthropogenically accelerated. For example in western Illinois, Caspall (1975) reported that under well managed grasses and legumes on spoil, a thin soil with an A horizon formed in 20 to 30 years. He suggested that tillage, by mixing and aerating spoil, would accelerate pedogenesis forming a similar soil in half the time.

In Illinois, Haynes and Klimstra (1975) studied the relationship between vegetation, reclamation success, and spoil properties as a function of spoil age. Table 13.1 shows organic matter, Na, and P accumulation in response to increasing spoil age and vegetation density.

Since it is not yet possible to study the effects of pedogenesis on Alberta spoils over long periods of time, in situ laboratory weathering simulation techniques must be used. Grube et al. (1973) for example reported several laboratory techniques for assessing spoil weathering rates including ultrasonic vibration, accentuated wetting and drying cycles, and acid generation in leaching columns. The

Table 13.1. Relationship of vegetation density and age with levels of organic matter, nitrogen, and phosphorus in spoilbank materials in Illinois.

Vegetation Density and Age Classes	No. of Samples	O.M. %	N[a] ppm.	P[b] ppm.
25%, 3 years	138			
Range		0.0 to 6.8	1.0 to 3620.0	2.0 to 47.0
Mean		0.99	690.51	7.96
SD		0.94	553.00	7.73
25%, 3 to 10 years	124			
Range		0.0 to 13.4	56.0 to 4340.0	2.0 to 93.0
Mean		1.43	840.38	12.57
SD		1.45	575.82	13.76
25%, 10 years	144			
Range		0.0 to 14.5	196.0 to 4508.0	1.0 to 185.0
Mean		1.81	992.57	19.17
SD		2.05	657.67	24.98
25%, 3 years	42			
Range		0.0 to 7.1	252.0 to 2191.0	2.0 to 58.0
Mean		1.04	636.71	10.19
SD		1.14	425.90	11.58
25%, 3 to 10 years	416	0.0 to 13.4	79.0 to 9828.0	2.0 to 67.0
Range		1.41	881.78	8.99
Mean		1.10	638.45	7.37
25%, 10 years	1220			
Range		0.0 to 13.7	1.0 to 5516.0	2.0 to 190.0
Mean		1.97	1117.95	11.02
SD		1.46	637.18	13.50

Source: Haynes and Klmstra (1975).
[a] Total nitrogen.
[b] Bray #1.

acidity potential can also be indicated for some acid spoils by measuring pyrite sulfur content after sulfate removal. Lavkulich et al. (1978) conducted artificial weathering tests by refluxing with water (Soxhlet extraction) and shaking with weak acids and bases.

One of the crucial initial pedogenetic processes which can occur is the rapid leaching of existing salts from spoil. Using calcareous and acid mine spoils from Ohio, Struthers (1965) used lysimeters to study salt leaching over a four year period. The quantity of salt leached decreased progressively over time. For the first year more salt was leached from the most toxic spoils and the least from agricultural soil. The dominant salts from the agricultural soil and calcareous and marginal spoils (pH > 3.0) were Ca and Mg; whereas for the toxic spoils (pH < 3.0) leached salts were rich in Fe, Al, and Mn (Table 13.2). With time the relative composition of the salt changed as Ca and Mg were depleted and Fe and Al were enriched under acid conditions.

In most spoils physical weathering tends to be more intense near the soil surface and can eventually cause a textural profile to develop with fines concentrated near the soil surface (Doubleday 1972). The rate of such textural profile formation will depend on the intensity of leaching and soil water flux.

Smith et al. (1974) reported for spoils in West Virginia that argillaceous sandstones, if geologically unaltered, are slow to weather and physical weathering occurred by the expansion-contraction actions of wetting and drying. Calcite sandstones tend to break down rapidly as carbonate is dissolved; however, quartz sandstone with about 20% carbonate remains intact. Clean sandstones, consisting of quartz cemented by secondary quartz material exhibits a range in rate of physical weathering. If the grains are rounded they are more easily separated because they are poorly bonded. If the grains are sharp the sandstone is more resistant to breakdown. The presence of natural bases inhibited sulfate formation and physical weathering more effectively than fly ash or $CaCO_3$, presumably because added bases lacked intimate contact with the pyrite.

Table 13.2. First-year yields of leached salts and metal ion components (kg/ha - 30 cm) from an agricultural soil and three spoil materials in in situ lysimeters in Ohio.

	Salts and components			
	Soil	Spoils		
		Calcareous[a]	Marginal	Toxic
Total salts	359	7 006	22 981	84 748
Calcium	74	1 457	4 596	1 121
Magnesium	70	751	1 457	8 408
Sodium	26	96	202	336
Potassium	4.0	31	55	87
Aluminum	0.3	0.2	68	2 130
Manganese	0.5	ND	135	2 578
Iron	ND	ND	0.9	493

Source: Adapted from Struthers (1964).

[a] pH = 7.5

Chemical weathering is closely controlled by the nature of the parent material or spoil and is equally site specfic. The role of chemical weathering in profile development is illustrated in research reported for acid mine coal spoil rich in clay in the U.K. (Doubleday 1972). If the shale is pyrite free, weathering is limited to physical breakdown of shale fragments, with minimal chemical weathering. If the shale contains pyrite and sufficient carbonates to stabilize soil pH near neutral, pyrite oxidation will result in amorphous ferric hydroxide formation and possibly goethite. When the shale lacks carbonates but has significant pyrite, surface soil pH and salinity become very high. These, however, decrease rapidly as soil depth increases. Jarosites form in horizons where pH values are less than 3.0, and ferric hydroxide forms at higher pH values.

The role of pyrite oxidation in acidification, salinization and NPK status of coal spoils has been studied extensively in England and the eastern United States.

Mays and Bengtson (1978) and Struthers (1965) discussed acidification of spoil by pyrite oxidation, the latter author presenting more detail.

Struthers (1965) studied the interaction between salt yield and soil pH during initial spoil weathering in a wide array of Ohio coal spoils. Generally the toxic spoils tended to have higher salt yields and pH < 3.0; however, surprisingly within the toxic and non-toxic spoil groups there was no relationship between salt yield and spoil pH.

Conversely, the non-toxic spoils contain more carbonate material or buffering capacity. Thus the non-toxic spoils release more calcium ions to the leachate while toxic spoils release higher levels of the metals (eg., Al, Fe, Mn; Figures 13.1 and 13.2). He also suggested the stability of spoils was difficult to predict in the initial phase of weathering; consequently, liming should be done only after the initial phase is over.

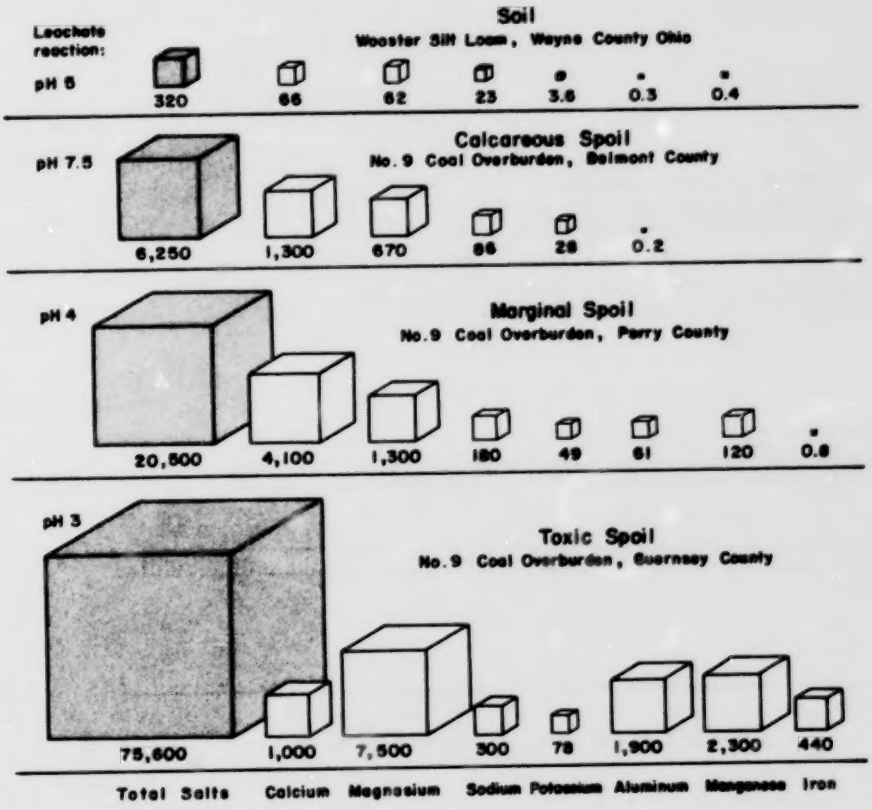

Figure 13.1. First-year yields of leached salts and metal ion components, in pounds, from four acre-feet of Ohio soil and spoil materials.

Source: Struthers (1965)

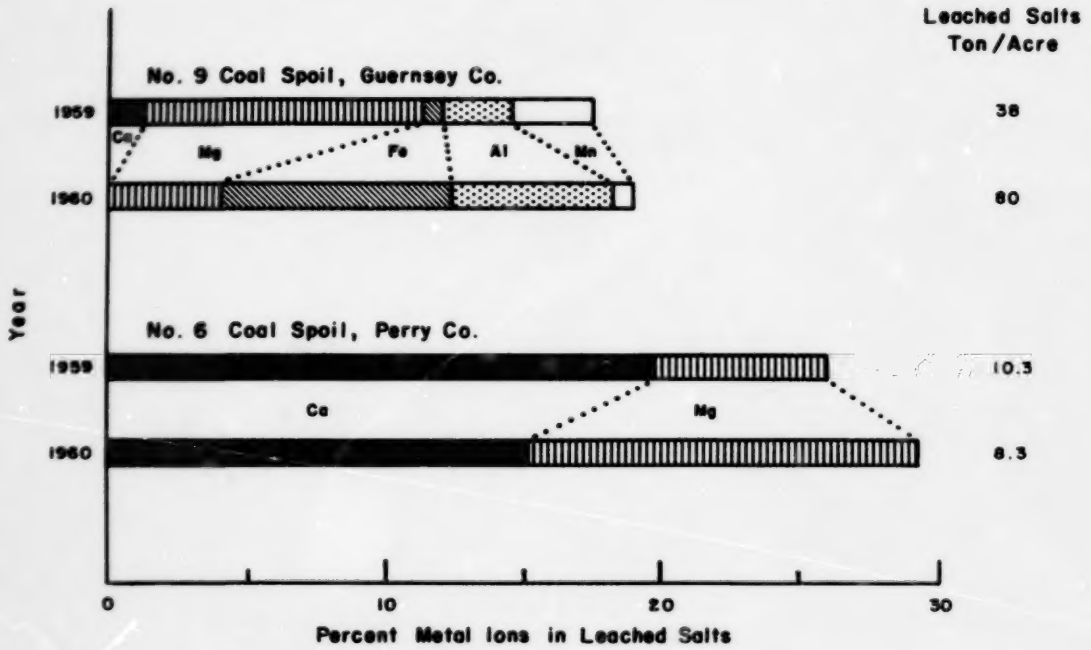

Figure 13.2. Changes in major components (over 1%) of salts leached during consecutive years from toxic and marginal Ohio spoil samples.

Source: Struthers (1965)

The effect of aging on acidic pyritic spoils in East Penmine, England was also studied by Palmer (1978). His results suggest a rapid acidification within two years followed by sustained acid conditions over many decades (Table 13.3). The distribution of measured pH values suggests this process is fairly uniform in this area. This acidity comes from oxidation of framboidal pyrite as the FeS_2 is unstable in the aerated spoil surface environment.

Thus,

$$FeS_2 + 7/2\ O_2 + H_2O \longrightarrow Fe^{++} + 2\ SO_4^{=} + 2H^+ \text{ and}$$

$$Fe\ S_2 + 15/4\ O_2 + 7/2\ H_2O \longrightarrow Fe(OH)_3 + 2\ SO_4^{=} + 4H^+$$

Sample calculations at one site showed oxidation rates of 0.32 g FeS_2 100 g^{-1} spoil a^{-1}. This would release about 11 meq of acidity 100 g^{-1} spoil and without natural buffering require about 12 t of $CaCO_3$ ha a^{-1} to neutralize. Practical experience seems to suggest such rapid oxidation only occurs in the initial one to three years and the lime requirement is not cumulative or recurrent. There is no commonly agreed hypothesis as to the dominant rate limiting processes to such oxidation.

Some work has been done on the pedogenesis of metal enriched tailings. However, metals in mine tailings are not presently a significant problem in Alberta. The ore deposit near Clear Hills is an iron hydroxide cemented sandstone therefore future mining should not produce sulphide tailings.

Michelutti (1974) studied the rather rare problems of acidification and oxidation of metal tailings from the Sudbury basin in Ontario. These tailings lack aggregation and are also deficient in nutrients and exchange capacity. Microflora are largely absent and toxic levels of heavy metals are prevalent. They are also subject to marked wind erosion. In extreme cases, capillary uptake has enriched selected metal concentrations near the spoil surface until a surface crusting phenomena, termed a ferruginous cap, develops. Acidification is by oxidation of S-rich pyrrhotite which produces sulfuric acid. The chemical composition of the surface oxidized layer is shown in Table 13.4.

Table 13.3. Spoil pH and surface age in acid pyritic coal spoils in England.

Site	Approximate age in years	Mean pH in 0.01M $CaCl_2$	Number of samples
Wooley (R)	0	7.16 ± 0.43	18
Gilcar (R)	0	6.21 ± 0.67	9
Gilcar (R)	1.5	3.08 ± 0.38	9
Water Haigh (R)	1.0	5.00 ± 0.88	16
Bullcroft	10	2.92 ± 0.30	12
Multby Maine	15	3.52 ± 0.56	24
Hound Hill	60	3.33 ± 0.23	12

Source: Palmer (1978).

R = Recontoured site.

Table 13.4. Analysis of nickel rim tailings, Sudbury basin, Ontario.

	Upper Oxidized Layer	Lower Unoxidized Layer
Magnesium	4.25 %	6.4 %
Sodium	0.16 %	1.64 %
Potassium	0.41 %	0.74 %
Calcium	4.44 %	5.53 %
Aluminum	2.3 %	3.2 %
Sulphur	6.23 %	2.31 %
Nickel	0.05 %	0.220 %
Copper	0.031%	0.063 %
Zinc	0.003%	0.0128%
Cobalt	0.041%	0.03 %
Iron	27.9 %	12.7 %
pH	3.0	4.5

Source: Michelutti (1974).

For South African gold and heavy metals mining spoil, Cresswell (1973) reported long term acidification in silty loam textured spoils (Table 13.5). He also reported the use of leaching or flushing prior to liming on very acidic sand textured spoils. In most of their spoils pH tended to stabilize between pH 5.5 to 6.5 without amending.

In old to very old acid spoils and in humid temperate climates other pedogenetic processes have been reported. In 70 to 130 year old acid coal mining spoils in Virginia, significant clay illuviation occurred as up to 10% of the clay was leached from the upper 10 cm of spoil and re-deposited at depths of 15 to 25 cm (Smith, Tryon and Tyner 1971). These data also suggested soil N accumulation by fixation under Melilotus alba and Robinia psuedoacacia of up to 22 to 34 kg/ha/a. Conversion of mica to vermiculite was also noted.

The most detailed work on spoil pedogenesis was undertaked by Down (1975b) on 0 to 180 year old acid coal spoil in the U.K. Subsurface analysis of unweathered rock material indicated that the spoil parent material of different aged spoils was very similar. Thus the spoils of different ages can be interpreted as different stages of pedogenesis of one spoil. The following trends were detected (Table 13.6): (1) water soluble heavy metals (Cu, Ni, Co, Zn, Mn) were not released in large quantities nor did release significantly change with spoil age; (2) water soluble levels of Ca and Mg tended to increase while Na levels decreased; (3) water soluble K initially declined then increased with age; (4) soil pH decreased for the first 12 years, stabilized for 43 years, then increased; (5) both PO_4 and soil N displayed losses followed by gradual increases with time; (6) soil organic matter increased linearly with time from 1% to 6% reaching a plateau after about 100 years; and (7) water soluble SO_4 levels varied inversely with pH levels (Table 13.7) as both were controlled by pyrite oxidation.

It is fairly clear that there was an initial period of intense leaching associated with acidification by pyrite oxidation. The free anions such as PO_4^{3-} and NO_3^- are leached most easily and completely. The weakly bonded cations Na^+ and K^+ are also markedly leached. Being

Table 13.5. Analysis of South African metal slimes; range of values in percent by weight except for pH.

Item	25-year-old gold slimes dam[a]	3-year-old uranium dam[b]
pH	2.5 to 3.1	6.5 and 7.3
N	0.02	0.02
P	0.023 to 0.046	0.050 and 0.060
K	0.24 to 0.30	0.32 and 0.64
Mg	0.71 to 0.85	1.24 and 1.54
Al	5.62 to 6.61	2.15 and 2.38
S	0.19 to 0.39	0.71 and 1.22
Ca	0.002	0.70 and 1.05
Fe	0.57 to 0.74	3.17 and 4.26
Mn	0.005	0.25 and 0.45
Zn	ND[c]	0.013 and 0.023
Cu	ND[c]	ND[c]
Mo	ND[c]	ND[c]
Boron (B_2O_3)	ND[c]	ND[c]
Co	ND[c]	ND[d]

Source: Data adapted by Cresswell (1973).

[a] Based on 3 samples.

[b] Based on 2 samples. Uranium dams are similar to gold slimes dams except that uranium is removed after the fold extraction.

[c] Not detectable.

[d] Trace.

Table 13.6. Soil property variation in spoils of different ages in the United Kingdom.

Spoil age (years)	Depth cm	Na	K	Mg	Ca	Mn	Ni	Cu	Fe	Co	Zn	PO_4 µg/g spoil	Org. C[a] %	Org. Matter %	N as mg $N\text{-}NH_4$/g spoil
0	0	40	84	44	11	0.4	0.4	0.1	0.3	1.0	1.0	} 42.5	} 0.46	0.79	13.0
	10	41	72	39	11	0.4	ND	0.1	0.1	1.0	1.0				16.0
	20	26	80	40	10	0.4	ND	0.1	0.2	1.0	2.0				14.0
5	0	46	8.0	72	45	6.0	0.4	ND	0.9	ND	4.0	21.3	0.87	1.52	11.0
	10	46	9.2	72	143	5.2	0.4	ND	0.8	ND	4.8	20.5	0.39	0.67	10.0
	20	33	4.0	50	122	5.2	0.4	0.8	0.8	1.0	5.6	30.3	0.37	0.64	8.0
12	0	33	12	72	14	5.0	0.4	0.1	0.1	1.0	4.4	26.7	1.04	1.81	50.0
	10	34	10	88	10	8.0	0.4	0.1	0.3	ND	4.4	25.7	0.58	1.01	47.0
	20	62	28	112	14	8.0	0.4	ND	0.2	ND	4.2	27.0	0.41	0.71	13.0
21	0	43	13	63	40	0.8	ND	ND	0.1	1.0	0.6	25.8	1.93	3.36	6.0
	10	44	14	50	50	0.4	0.4	ND	0.1	1.0	0.4	27.8	0.57	0.99	8.0
	20	44	13	44	55	0.4	ND	ND	ND	1.0	0.4	26.7	0.44	0.77	11.0
45	0	44	28	32	35	2.8	ND	ND	0.1	1.0	0.8	24.7	2.35	4.09	11.0
	10	35	32	60	55	3.2	0.4	0.8	ND	ND	3.4	28.2	0.98	1.71	8.0
	20	35	40	104	45	1.0	ND	0.4	ND	ND	1.6	29.5	0.45	0.78	6.0
55	0	36	28	56	55	0.4	ND	0.1	ND	ND	0.4	32.0	3.47	5.04	13.0
	10	35	33	60	45	0.4	ND	0.1	ND	ND	0.4	34.0	1.12	1.95	10.0
	20	33	32	116	50	0.4	ND	ND	ND	1.0	0.8	34.7	0.38	0.66	8.0
98	0	34	79	136	61	1.0	ND	ND	0.1	1.0	0.4	42.7	3.99	6.25	9.0
	10	35	68	172	55	0.8	ND	0.4	ND	ND	0.4	47.3	1.33	2.32	10.0
	20	34	57	96	61	0.8	ND	0.1	ND	ND	1.4	45.7	0.35	0.61	8.0
178	0	32	62	160	65	0.4	ND	ND	ND	ND	0.4	48.0	4.02	6.35	40.0
	10	33	64	179	72	0.4	ND	ND	ND	ND	0.4	47.7	1.45	2.53	52.0
	20	33	58	182	84	0.4	ND	ND	ND	ND	0.4	48.0	0.65	1.13	50.0

Source: Adapted from Down (1975b)

[a] Means listed, SE of mean listed in original paper.

Table 13.7. Variation in soil acidity properties in spoils of different ages in the United Kingdom.

Spoil Age (years)	pH[b] (in $CaCl_2$)	SO_4[a] (ppm)
0	7.28	30.62
5	2.57	93.10
12	3.37	63.00
15	4.22	19.50
21	3.84	21.32
45	3.54	40.10
55	4.50	17.50
98	5.56	2.06
178	5.92	12.25

Source: Down (1975b).

a Mean is shown, SE of mean is listed in original paper, distilled water is also listed in original paper.

b Water soluble sulfate; means are shown, SE of mean is listed in original paper.

more strongly bonded to soil (micelle) surfaces, Ca^{2+} and Mg^{2+} are less affected. Then from 10 to 50 years pyrite oxidation slows down and the acidification stops. Humification, possibly including minimal conversion of coal to soil organic matter (Down 1975a), becomes the dominant pedogenetic process. This is suggested by the systematic decrease in coal content with time (Tables 13.8, 13.9; Down 1975a) and concomitant increase in soil organic matter (Table 13.6) levels. The fact that most of the coal is lost from the fine fraction further supports this hypothesis (Table 13.8; Down 1975a). As organic matter accumulates it bonds the more mobile cations, such as K^{+}, PO_4^{3-}, and NH_4^{+}, and cycles them through plant and microbial populations. Although not discussed, weathering of the spoil would be expected to increase the fine fractions of the soil texture and enhance long term humification. For example, finer soil textures would increase the soil surface area and would in turn increase moisture and nutrient retention thereby decreasing nutrient leaching and illuviation of organic matter.

Changes in the surface layers of coal spoil were reported by Down (1975a) for Somerset, England where much of the particle breakdown occurred at the surface in the first 20 years. Below this surface layer particle breakdown was markedly slower (Tables 9.1 and 13.10).

As the large cobbles on the surface are broken down fines (<45 μ) began to accumulate at the soil surface along with coarse sand. The data suggest a textural Ae or eluvial A horizon, which is low in fines, is formed during this initial 20 years. After 50 years of aging it appears this Ae horizon begins to disappear as fines formed at the surface are eluviated down the profile. Conversely where sheet erosion occurs spoil textures can become coarser with time (Fitzgibbon 1976; see Chapter 10).

13.1 SUMMARY

Pedogenesis may improve nutrient status by increasing macro- and micronutrient levels, increasing organic matter accumulation, and ameliorating chemical problems such as acidity. Conversely, pedogenesis

Table 13.8. Coal content of tip spoil in the United Kingdom.

Spoil age (years)	Depth (cm)	Coal content (%)	Mean
0	All	53.62	
5	0	21.82	
	10	30.92	
	20	28.05	26.93
12	0	18.89	
	10	32.01	
	20	21.30	24.07
21	0	11.67	
	10	38.63	
	20	43.13	31.14
45	0	7.55	
	10	13.32	
	20	11.07	10.64
55	0	2.45	
	10	10.52	
	20	18.41	10.46
98	0	12.75	
	10	20.94	
	20	23.73	19.14
178	0	15.41	
	10	20.72	
	20	20.77	18.97

Source: Adapted from Down (1975a)

Table 13.9. Coal distribution in size fractions from spoils in the United Kingdom.

Spoil particle size (μ)	Coal content (%)	
	0-year-old tip	98-year-old tip
Above 9530	43.38	45.16
9530 to 4000	29.31	14.25
4000 to 2000	34.06	27.41
2000 to 1000	39.69	25.10
1000 to 500	48.22	28.54
500 to 210	58.28	29.18
210 to 125	56.38	29.20
125 to 63	54.93	28.51
63 to 45	63.96	27.22
Below 45	52.85	23.35

Source: Down (1975a)

Table 13.10. Percentage of spoil particles larger than 9530 μ in spoil samples in the United Kingdom.

Spoil age (years)	Depth		
	50 cm	75 cm	100 cm
0	43.0	43.8	42.5
98	37.9	34.2	54.1
178	47.2	47.2	45.9

Source: Down (1975a)

can worsen fertility by increasing heavy metal levels, releasing excessive salts, or deteriorating structure.

Changes in spoils may occur in as little as 10 years. Vegetation promotes pedogenesis through erosion protection and addition of organic matter. Cultural practices, such as tillage, can also accelerate pedogenesis.

Leaching of salts is a critical initial pedogenic process. The process can improve spoil but deteriorate groundwater.

Materials weather physically at different rates and thus rates of pedogenesis vary. Chemical characteristics of spoil materials are also important (e.g., acid forming materials). Chemical weathering processes are often very complex and can result in highly variable products of pedogenesis from seemingly similar materials. Because stability of spoils is difficult to predict in the initial stage of weathering, it may often be wise to delay application of amendments until initial phases of weathering are complete. Where historical records are absent, laboratory simulation may be useful for predicting weathering rates and products.

Different mechanisms of pedogenesis occur over time. For example, pedogenesis may begin with leaching, accompanied and followed by chemical weathering (oxidation), humification and finally a change in soil texture to more fines, resulting in stability of moisture and nutrient status. These processes may occur in 100 to 200 years or less.

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14. RECLAMATION SUBSTRATE QUALITY RATING

The concept of developing a system for rating in situ premining substrates, primarily soils and overburden, as to their suitability for reclamation overlaps all substrate properties--chemical, physical, and biological. It also encompasses the utilization of amendments.

Land use capability systems have long been used to plan land based resource allocation and development. The most well known and oldest system in Canada is the land use capability mapping for agriculture. Similar approaches have been developed in Canada for forestry, recreation, and urban soil uses. In addition, more specific schemes such as suitability of land for septic systems have been proposed, and an extensive system oriented towards engineering applications has recently been developed at the Land Resource Research Institute in Ottawa. Almost all this work has been focussed on mineral soils. Some limited work has also been done in Canada on capability systems of organic soils, the most recent of which includes assessments for industrial applications such as peat fuel and horticultural peat in addition to the traditional in situ agriculture.

Although the objectives for developing a rating system for reclamation in Alberta are different from the objectives of the previously mentioned systems, the principles of all rating systems are similar. The basic principles of rating systems are that by assessing the natural properties of ecosystems, the effects of disturbance by alternative uses, and ecosystem rehabilitation, one can plan utilization to maximize social benefit from such resources.

The objective of a reclamation capability system for soil and overburden is to define the role of existing materials in the future reconstructed soil. The system must allow for prediction of the physical, chemical, and biological productivity of the reconstructed soil based on the various alternatives. It must also allow for manipulation, in a formula, of the amendments, original soil, and overburden materials in such a way as to produce a reclaimed soil of equal or superior capability to the original, having long term,

self-sustaining properties. From an operational point of view this involves: (1) assessing the productivity and fertility of existing soils and overburden (i.e., a productivity inventory); (2) assessing the impact of mixing, handling, and storage on productivity and the minimization of such activities; (3) defining the difference between reconstruction with existing stored material and the original productivity and stability; and (4) amending to correct the difference.

Some initial research and simple reclamation rating systems have been proposed. Guidelines for agricultural use of saline soil have been developed in the United States and in Canada (e.g., Table 14.1). From information such as this many systems for rating materials suitable for reclamation have been developed. The systems developed by McAllister (1977), Omodt, Schroer and Patterson (1975), and Sandoval et al. (1973) are examples of such developments.

Dollhopf, Jensen and Hodder (1977) and Sandoval et al. (1973) have among others, broadened these systems to include an assessment of nutrient deficiencies and toxicities. Some authors have also looked at the importance of physical and moisture related properties in reclamation rating systems (Christie 1980; Regier 1976).

In western North Dakota, Omodt, Schroer and Patterson (1975) developed a quantitative classification or rating system for premined agricultural soils. They used the system to assess both the productivity of existing soils and the suitability of various horizons and depth requirements for reconstructing soils. Organic matter content, salinity, free lime, and exchangeable sodium were their primary criteria as shown in Table 14.2. Figure 14.1 shows the application of these criteria to several different typical soil series in North Dakota.

Omodt, Schroer and Patterson used this system and extensive soil survey data to define a feasible and suitable reconstructed soil profile as follows:

Table 14.1. Interpretation of salinity and sodium-adsorption-ratio levels in relation to the suitability of soils for agricultural use.

Suitability	Horizons	Salinity [a]	SAR [b]
Satisfactory	A, B	< 4	< 6
	C to 10 cm	< 4	< 8
Fair	A, B	< 4	< 6
	C to 10 cm	< 8	< 8
Poor	A, B	< 8	< 8
	C to 10 cm	< 12	< 12
Very poor	A, B	> 8	> 12
	C to 10 cm	> 15	> 15

Source: Canada Department of Agriculture (1964)

[a] Electrical conductivity, expressed as millimhos (mmhos) per cm of saturated soil solution at 25°C, is a direct measurement of soluble salt concentration.

[b] Sodium-adsorption-ratio (SAR) is defined as $\frac{Na^{+}}{\sqrt{(Ca^{++} + Mg^{++})/2}}$ where the cations indicated are expressed in millequivalents per litre. The SAR value provides a close indication of the exchangeable-sodium-percentage in most soils.

Table 14.2. Rating system of agricultural soils in western North Dakota for reclamation suitability.

Class	Reclamation limitation	Criteria			
		Organic Matter %	salinity EC mmhos/cm	free lime %	exchangeable Na %
1	none	≥2	<2	<1	<5
2	slight	1-2	2-4	1-10	5-12
3	moderate	<1	4-8	>10	>12
4	severe		>8		

Source: Omodt, Schroer and Patterson (1975)

Table 14.3. Reclamation criteria for plains soils.

Property No.	Substrate Property	Substrate value	Environmental Constraint	Reclamation Rating
1.	EC	<4	slight plant effects	favourable
		4-8	moderate plant effects	moderately favourable
		>8	severe plant effects	unfavourable
2.	SAR	4	no plant or soil structure effect	favourable
		4-10	moderate plant and structure problems	moderately favourable
		10-15	puddling, Na toxicity	unfavourable
3.	θ_{vsat_1}	45-65% vol.	adequate moisture supply	favourable
		<45	inadequate moisture supply drought	unfavourable
		>80	excessive moisture supply oxygen deficiency	unfavourable

Source: Adapted from McAllister (1977)

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1 θ_{vsat} is the saturation percentage.

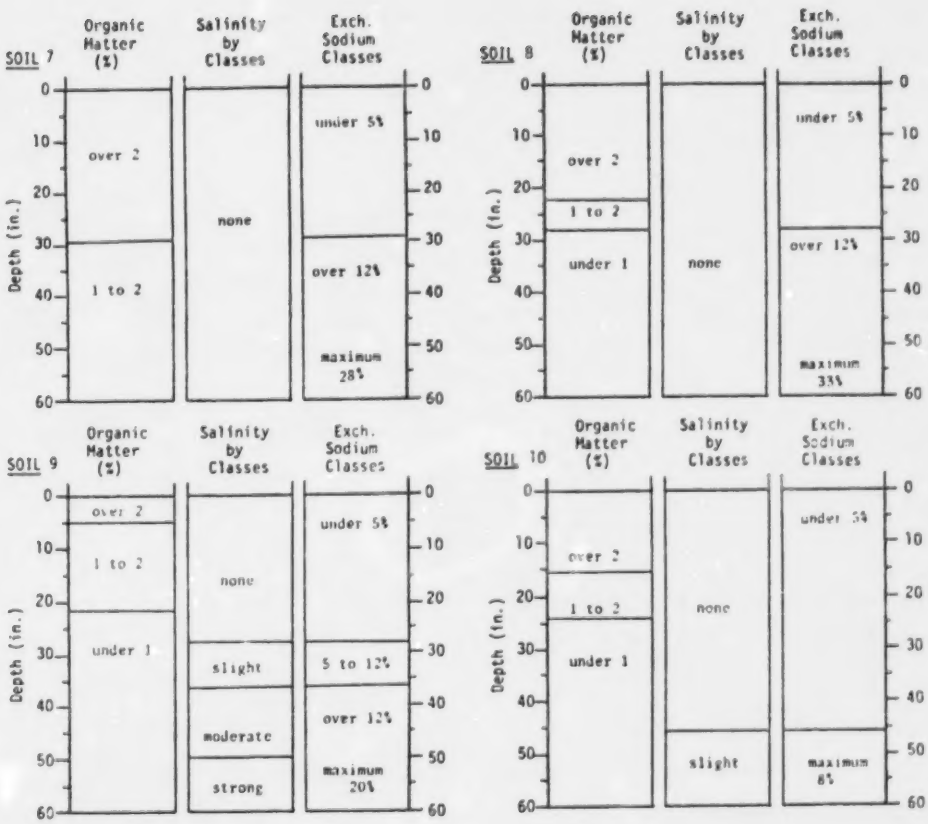

Figure 14.1. Organic matter content, salinity, and exchangeable sodium percentage by depths and classes of these properties for four North Dakota soils.

Source: Omodt, Schroer and Patterson (1975)

soil depth in cm	minimum quality limits for soil properties
20 to 25	(i) 2% organic matter (ii) non saline (iii) EC ≤ 2 (iv) exchangeable Na < 5% (v) free lime < 10%
25 to 60	(i) slightly saline (ii) exchangeable Na < 12% (iii) free lime can be variable
> 60	(i) levelled spoil

They also identified the need for sustained management of reclaimed spoil by treatments such as tilling and chiselling fine textured materials.

McAllister (1977) presented a scheme for rating soils, primarily those salt affected soils in the plains regions of Alberta. He used electrical conductivity (EC), sodium adsorption ratio (SAR), and volumetric soil moisture content at saturation (θ_{vsat}) to rate the suitability of soil and overburden materials for reclamation. These materials are summarized in Table 14.3. The author applied these criteria to several soils and overburden types as shown in Table 14.4. He also attempted to evaluate techniques for improving the quality or rating of unfavourable overburden. McAllister compared blending or mixing specific amendments with overburden to topsoiling or covering the overburden with amendments.

The Montana guide for rating soil material and overburden for reclamation includes nine criteria for soils and 21 criteria for overburden (Dollhopf, Jensen and Hodder 1977; Table 14.5). Included are measurements indicative of saline soil problems and those

Table 14.4. Rating plains soils for reclamation suitability.

Example Rating No.	Soil	Overburden	Reclamation Criteria EC	SAR	θ_{vsat} (% by weight)	Overall
1.	Eluviated Black	alluvial cacustrine	<4	<4	60	favourable
2.	Solonetzic	Residual Edmonton formation	2-12	16-24	80-140	unfavourable
3.	Eluviated	Glacial till from Edmonton formation	<2	<8	60	ideal
4.	Gleysolic	Glacial till from Edmonton formation	4-8	8-14	80-100	moderately unfavourable

Source: Adapted from McAllister (1977)

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Table 14.5. Montana criteria used in guide for rating soil material for use as a final plant growth medium cover for mined land.

Criteria	Sampling scheme: Soil survey 30 cm increment to 180 cm depth	Sampling scheme: Overburden 3 m increment	Suspect Level	Laboratory procedure
1	Saturation %	Saturation %		U.S.D.A. Handbook 60, p.84, method 2 & 3a.
2	Mechanical analysis	Mechanical analysis	clay >40%	A.S.A. Agronomy Monograph No.9, Method 43-5, p. 563-566.
3	Conductivity	Conductivity	>4mmhos/cm	U.S.D.A. Handbook 60, p. 88-89.
4	pH	pH	>8.3	U.S.D.A. Handbook 60, p. 102.
5	Ca	Ca		U.S.D.A. Handbook 60, p. 84, method 2 & 3a. Atomic Absorption Spectrophotometry.
6	Mg	Mg		Same as Ca.
7	Na	Na		Same as Ca.
8	SAR	SAR	>10	as meq/L $Na/\ [(Ca + Mg)/2]^{1/2}$
9	B	B	8 ppm	Hot water extraction with B free condenser tubes.
10		NO_3-N	10 ppm	A.S.A. Agronomy Monograph No.9, p. 1212, method 84-5.3.
11		NH_4-N	10 ppm	Jackson, M.A. 1958. Soil chem. anal., Prentice Hall, Inc. P. 19, 194-195.
12		Se	2 ppm	$NaBH_4$ extraction, atomic absorption.
13		Mo	0.3 ppm	A.S.A. Agronomy Monograph No.9, p. 1054-1057, method 74-2.
14		Hg	500 ppb	Gaseous hydride-hot water extraction. EPA. 1774. Meth. chem. anal. of water and wastes.
15		Zn	40 ppm	DTPA Extractable. SSSAP, Vol. 35, No. 4, 1971, p. 600-602.
16		Mn	60 ppm	Same as Zn.
17		Cu	40 ppm	Same as Zn.
18		Cd	1 ppm	Same as Zn.
19		Pb	5 ppm	Same as Zn.
20		Ni	1 ppm	Same as Zn.
21		PO_4-P		$NaHCO^3$ extraction. Olsen, S.R. 1954. U.S.D.A. Circular No. 939 March.

Source: Dollhopf, Jensen and Hodder (1977)

measurements likely to detect potential nutrient deficiencies and toxicities. It is noteworthy that organic carbon, CEC, and carbonate or free lime are not mentioned.

Sandoval et al. (1973) developed a more detailed rating system for similar soils that included more criteria (Table 14.6). The application of these criteria to several soils and overburden types and the resultant reclamation suitability rating are shown in Tables 14.7 and 14.8.

In arid regions such as the Great Plains and much of Alberta the physical and chemical properties of some overburden layers may be so toxic or undesirable that excluding these materials from the reconstructed soil and placing them well below the soil profile may become the paramount concern. In these situations a knowledge of the overburden characteristics and stratigraphic location on the geologic profile may be so crucial that they are used as the only criteria (excluding productivity of other materials) in evaluating and planning materials handling for reclaiming spoil.

The converse situation is also possible--where the physical and chemical properties of some overburden layers may be deemed highly desirable and the primary materials handling objective becomes ensuring that these materials are included in the reconstructed soil. Regier (1976), for example, found that the percentages of available moisture, percentage of clay, and CEC in Athabasca tar sands overburden were highly correlated, thus suggesting moisture saturation percentage of overburden could be used as an overburden selection criterion for reclamation material. Both peat and fine textured mineral soil amendments would therefore improve moisture and nutrient retention of reclaimed tailings sand.

The U.S. Department of Agriculture, Soil Conservation Service (1971) has developed guidelines for application of soil survey type data to engineering applications. Similar work is in preparation by N. Wilson at Agriculture Canada's Land Resource Research Institute in Ottawa, Canada. Christie (1980) developed a soil suitability for reclamation system for British Columbia mining soils patterned on the

Table 14.6. Reclamation criteria for plains soils.

Property No.	Substrate Property	Substrate value	Environmental Constraint	Reclamation Rating
1.	pH	6.0-8.0	near neutral no problems	ideal
		>8.0	salinity and alkalinity problems	unfavourable
2.	$CaCO_3$	>5.0%	Ca replaces Na on exchange complex	favourable
		<5.0	Sodium toxicity, puddling problem	unfavourable
3.	clay texture	> 40%	poor tilth, low infiltration, excessive soil moisture	unfavourable
		< 40	less structure moisture problem	favourable
4.	θ_{vsat}	> 80%	poor aeration, oxygen deficiency	unfavourable
		< 80		favourable
5.	EC	< 2	no problems	ideal
		2-4	slightly saline	moderately favourable
		4-8	moderately saline	moderately unfavourable
		8-16	severely saline only salt tolerant plants grow	unfavourable
		< 16	no plant growth possible	unsuitable
6.	SAR	> 12	potential sodium toxicity and salinity problems	unfavourable
		< 12	no problems	favourable
7.	(NH_4 & NO_3) Plant available N	> 10 ppm	no N deficiency	ideal
		3-10	moderate N limiting	moderately favourable
		< 3	severe N deficiency	unfavourable

Source: Sandoval et al. (1973)

Table 14.7. Characterization and reclamation rating of normal topsoil and surface spoil pile materials from strip mine areas in western North Dakota, northwestern Wyoming, and eastern Montana.

Number	Location	pH	$CaCO_3$ (equiv) %	Particle size[a] Sand %	Silt %	Clay %	Saturation extract Sat'n %	EC mmhos	Ca meq/L	Mg meq/L	Na meq/L	SAR	CO_3,[b] HCO_3 meq/L	SO_4 meq/L	Environmental Constraints	Reclamation rating
Topsoil																
1	Stanton, N.D.	6.8	<1	40	45	25	43	<1	3	2	1	<1	1	4	no problem	ideal
2	Zap, N.D.	7.3	1	41	39	20	36	<1	5	3	1	<1	4	3		
Spoil																
3	Beulah, N.D.	8.4	12	14	49	37	141	3	<1	<1	34	41	5	30	very wet, high SO_4 levels	unfavourable
4	Beulah, N.D.	8.1	13	8	51	41	115	6	4	5	52	24	3	55	very high Na and SAR levels	
5	Beulah, N.D.	8.3	8	27	21	52	178	3	1	1	34	34	6	28	moderate salinity and EB	
6	Center, N.D.	7.6	10	24	50	26	57	4	14	29	7	2	2	40	high SO_4 levels, slightly alkaline pH	moderately unfavourable
7	Stanton, N.D.	8.3	ND[c]	ND	ND	ND	156	2	<1	<1	22	27	3	21	very high Na and SAR levels	unfavourable
8	Stanton, N.D.	8.3	ND	12	36	52	144	2	1	1	20	19	6	16	very wet, high to very alkaline pH	
9	Zap, N.D.	8.5	ND	ND	ND	ND	78	2	<1	<1	16	37	7	10		
10	Zap, N.D.	8.8	10	3	43	54	160	2	<1	<1	19	48	10	7		
11	Cascayne, N.D.	8.1	ND	ND	ND	ND	41	8	6	15	74	23	ND	ND	very high Na levels, saline EC	moderately unfavourable
12	Gillette, Wyo.	7.4	ND	ND	ND	ND	33	8	25	73	31	5	ND	ND		
13	Sheridan, Wyo.	6.1	ND	ND	ND	ND	50	7	29	28	45	8	ND	ND	slightly saline EC	moderately unfavourable
14	Colstrip, Mont.	7.2	ND	ND	ND	ND	48	3	15	19	3	<1	ND	ND		

Source: Adapted from Sandoval et al. (1973)

[a] Particle size: Sand -->0.05 mm; silt = 0.05 - 0.0002 mm; clay -<0.002 mm.

[b] Sample No. 3 through 10 originated from depths greater than 50 feet; original depth of No. 11 through 14 unknown.

[c] ND = analysis not determined

Table 14.8. Characterization and reclamation rating of overburden at three sites in western North Dakota before disturbance by mining.

Depth	pH	$CaCO_3$ equiv. %	Sat'n %	E. Cond. mmhos	SAR	Nitrogen NH_4-N ppm	Nitrogen NO_3-N ppm	Environmental constraint	Reclamation rating
Stanton No. 1, Level Site									
0 to 0.2	7.6	2	70	1	1	ND	ND	low plant available N	favourable
0.2 to 3.3	7.6	13	46	2	1	1	2	low plant available N	favourable
3.3 to 6.1	7.4	8	86	5	7	2	11	slightly saline EC	moderately favourable
6.1 to 9.1	8.2	13	122	2	15	2	2		
9.1 to 17.4	8.5	10	150	2	39	12	2		
17.4 to 21.3[a]	7.1	14	--	3	52	13	2	very high SAR, very wet	unfavourable
21.3 to 27.4	8.2	13	180	1	34	14	1		
27.4 to 29.9[a]	6.8	10	--	3	25	16	2	neutral to fairly alkaline pH	
29.9 to 32.0	7.6	11	161	1	25	14	2		
Stanton No. 2, Hilly Site									
0 to 0.9	7.0	2	50	2	2	1	1	low plant available N	favourable
0.9 to 3.0	8.2	15	128	8	13	3	6	very wet, alkaline pH, saline EC	
3.0 to 5.5	8.0	7	181	5	15	2	34	high SAR	unfavourable
5.5 to 7.0[a]	4.5	3	--	9	15	5	37	very acidic pH, saline EC, high SAR	unfavourable
7.0 to 15.2	7.7	11	142	3	31	10	2		
15.2 to 18.3[a]	6.9	8	--	5	30	16	3	neutral to alkaline pH, very wet	
18.3 to 29.3	8.1	13	164	2	30	15	2	very high SAR, slightly to moderately	unfavourable
29.3 to 31.7[a]	7.0	11	--	2	22	16	2	saline EC	
31.7 to 33.2	7.5	5	158	2	25	17	2		
Glovo Site[b]									
0 to 6.1	7.7	3	87	3	2	5	1	slightly wet, moderate N limitation	favourable
6.1 to 12.2	7.9	10	95	1	9	18	1	slightly wet, slightly saline	moderately favourable
12.2 to 24.4	7.6	10	95	3	25	17	1	slightly alkaline pH, slightly to very	unfavourable
24.4 to 36.6[a]	7.9	5	174	2	50	15	1	wet, very high SAR	
36.6 to 48.8	8.5	13	138	2	54	24	1		
48.8 to 61.1	8.4	7	133	2	53	25	1	markedly alkaline pH, very wet	
61.1 to 91.4[a]	8.2	10	142	2	62	28	1	very high SAR	unfavourable
91.4 to 121.9	8.3	7	119	2	53	15	1		
121.9 to 152.4	8.6	9	128	2	50	14	1		

Source: Adapted from Sandoval et al. (1973a)

[a] Layers with lignite.

[b] Sampling by courtesy of U.S. Forest Service, Dickinson, N. Dak.
The lithologic log shows major lignite layers at 34.7 to 36.6, 85.3 to 91.4, and 103.6 to 121.9 m.

U.S. Department of Agriculture, Soil Conservation Service system. His system incorporates both soil survey data and site specific analytical data; however, it is limited to rating in situ natural soils as cover material for spoil and does not address the role of amendments and degree of suitability or toxicity of the spoil itself. Table 14.9 is a summary of his reclamation rating system showing its criteria. Table 14.10 gives an example of the rating system application to soils in British Columbia.

One of the most complete reclamation rating systems is the one developed by Alberta's Soil Quality Criteria Subcommittee (1981). In 1978, a Soil Quality Criteria Subcommittee (Stage II) (SQCS) was formed by the Alberta Soils Advisory Committee (ASAC) to address the problem of assessing the quality of disturbed soils in Alberta. The results of these endeavours are unique for the following reasons:

1. A broad spectrum of experience and institutional viewpoints was incorporated.
2. Guidelines were developed which will be part of an ongoing process of continued refinement and updating; a first approximation only was the objective.
3. The guidelines are intended to be used province wide.
4. Empirical testing of guidelines has been and will be done intensively over a broad range of site conditions and locations.

Specifically the terms of reference which the SQCS addressed were to develop guidelines relative to:

1. soil mapping and sampling for baseline and post disturbance activity;
2. overburden sampling;
3. analytical requirements; and
4. physical, chemical, and biological criteria for evaluating the suitability of soil materials for revegetation.

Table 14.9. Suitability ratings of soils as sources of cover material for mine waste reclamation.

Item affecting use	Degree of soil suitability		
	Good	Fair	Poor
Texture	SL L SiL SC L	SiCL CL SC LS	SiC C S peat muck
Moist consistence	Very friable	Loose, firm	Very firm; extremely firm
Coarse fragment content	<15%	15 to 35%	>35%
Stoniness class	Non-stony, slightly stony (classes 0, 1)	Moderately to very stony (classes 2, 3)	Exceedingly to excessively stony (classes 4, 5)
Drainage class	Not limiting if better than poorly drained		Poorly drained and very poorly drained
Thickness of material	>100 cm	50 to 100 cm	<50 cm
Soluble salts (Electrical conductivity)	<4 mmhos/cm	4 to 8 mmhos/cm	>8 mmhos/cm
Reaction class (pH in water)	Slightly acid to mildly alkaline (6 to 8)	Medium acid (5.5 to 6) mildly alkaline (7.5 to 8)	Strongly to very strongly acid (4.5 to 5.5) moderately alkaline to strongly alkaline (8 to 9)
Cation exchange capacity (meq/100 g soil)	>25	15 to 25	<15

Source: Christie (1980)

Table 14.10. Application of Christie's (1980) rating system to British Columbia soils.

Mapping Unit	Terrain	Texture	Soil Drainage	Soil Classification	Significant Characteristics	Suitability as source of cover material
1	Morainal blanket	CL / C	MW	BR.GL	Highly compacted ground moraine at depths 100 cm	Poor
1A	Morainal blanket	C	MW	GL	Severe erosion, rapid runoff	Nil
1B	Morainal blanket	C	MW	BR.GL	Pitted and hummocky capping of GS veneer	Poor
2	Morainal blanket	GSL	W	BR.GL	Inclusions of coarse textured morainal veneer	Fair
3	Morainal blanket	SCL	W	BR.GL		Good
4	Glaciofluvial veneer over morainal blanket	VGS / SCL	W-R	O.DYB	Excessively stony and gravelly	Poor
5	Glaciofluvial blanket; ridged	GS	R	O.DYB	Moderately stony	Poor
6	Organic	MESIC	VP	TY.M	Inclusions of well humified forms and calcareous layers	Nil but useful as soil amendment
7	Morainal veneer over glaciofluvial blanket	GCL / GSL	W-R	O.DYB	Morainal veneer is discontinuous	Fair

Source: Christie (1980)

The following responsibilities also became part of the purview of the subcommittee:

1. preparation of a glossary of soil terms relevant to the above subject matter;
2. delineation of the province into broad ecological zones so that relevant guidelines and criteria could be established for the major regions; and
3. development of recommendations for future action and research.

In May 1981, a document entitled "Proposed Soil Quality Criteria in Reclamation" was published (Soil Quality Criteria Subcommittee 1981), presented, and discussed in an Alberta Land Conservation and Reclamtion Council Workshop. Since it is written in a terse, detailed style this document is not easily summarized. Thus only a brief outline is presented here and a full comprehension of it can only be gained by studying the document in its entirety.

As an initial step the province was divided into three ecological zones: (1) the plains region including the central plains and Peace River plains; (2) the eastern slopes region including the lower and upper foothills and the Rocky Mountains to the British Columbia border; and (3) the northern forested region including the remainder of the province (Figure 14.2).

Different objectives have been developed for each region as each region represents different requirements and problems for reclamation. This in turn results in different mapping, sampling, and criteria for materials evaluation. Table 14.11 for example, describes the type of soil survey required in each of the three regions for baseline information and general planning purposes.

Sampling and analytical requirements are described in detail using standard methodology (Tables 14.11 and 14.12). The sampling depth required to establish soil quality criteria varied among regions (Table 14.13). For brevity the criteria developed for the Plains region only are presented. Conceptually it is assumed that the reconstructed soil consists of topsoil overlying subsoil, which in turn

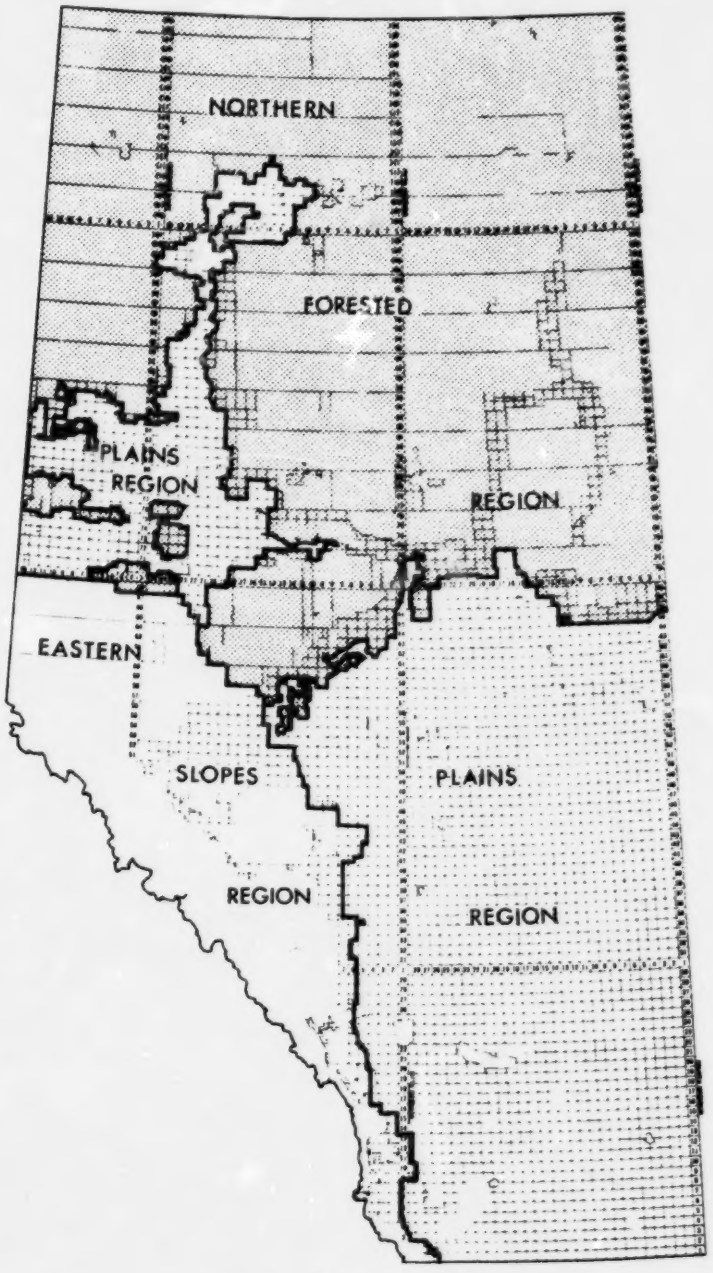

Figure 14.2. Land regions of Alberta.

Source: Soil Quality Criteria Subcommittee (1981)

Table 14.11. Proposed guidelines for conducting soil surveys relative to development and reclamation, in Alberta.

Region	Purpose of Mapping	Level of Survey	Recommended Scale	Min. size area represented by 1 cm² on map (ha)	Inspection Density (ha/insp.)	Sampling[a] Density (profile sites) ha/sample	Overburden Sampling ha/sample site
PLAINS	Baseline	2	1:10 000 to 1:20 000	1 4	1 to 5 4 to 20	10 to 50 40 to 200	150 to 300 250 to 400
	Post disturbance (Derelict)	1	1:3 000 to 1:5 000	0.09 0.25	0.09 to 0.45 0.25 to 1.25	0.45 to 2.25 1.25 to 6.25	ND ND
	Post disturbance (Materials handling)	1	1:5 000 to 1:7 500	0.25 0.50	0.25 to 1.25 0.50 to 2.5	2.5 to 12.5 5 to 25	ND ND
EASTERN SLOPES	Baseline	2	1:10 000 to 1:20 000	1 4	1 to 5 4 to 20	5 to 25 20 to 100	150 to 300 250 to 400
	Post disturbance (Derelict)	1	1:3 000 to 1:5 000	0.09 0.25	0.09 to 0.45 0.25 to 1.25	0.45 to 2.25 1.25 to 5.0	ND ND
	Post disturbance (Materials handling)	1	1:5 000 to 1:10 000	0.25 1	0.25 to 1.25 1 to 5	2.5 to 12.5 10 to 50	ND ND
NORTHERN FOREST	Baseline	2	1:20 000 to 1:30 000	4 9	4 to 20 9 to 45	40 to 200 90 to 450	250 to 400 400 to 600
	Post disturbance (Derelict)	1	1:5 000 to 1:7 500	0.25 0.50	0.25 to 1.25 0.5 to 2.5	1.25 to 6.25 2.5 to 12.5	ND ND
	Post disturbance (Materials handling)	1	1:7 500 to 1:10 000	0.50 1	0.5 to 2.5 1 to 5	5 to 25 10 to 50	ND ND

Source: Soil Quality Criteria Subcommittee (1981)

[a] Sampling density = at least 50% of the sample sites should be comprised of complete profiles.

Table 14.12. Analytical requirements for disturbed lands and derelict areas.

Analyses	Notes	Preferred Method	Acceptable Method
pH	0 to 15, 15 t0 30, 30 to 60, and 60 to 90 cm depths	3.11[a]	3.14, 3.13
Specific percentage[b]	All depths sampled	3.21	
Specific conductance[b]	All depths sampled	3.21	
Soluble cations (Ca, Mg, Na, K) and SAR[b]	All depths sampled	3.21	
Phosphorus (available)	0 to 15, 15 to 30, 30 to 60, and 60 to 90 cm depths	4.44	4.41, 4.42
Nitrate	0 to 15, 15 to 30, 30 to 60, and 60 to 90 cm depths	4.35	4.32
Ammonium	0 to 15, 15 to 30, 30 to 60 and 60 to 90 cm depths	4.35	
Macronutrients--Heavy metals Fe, Zn, Cu, Mn, Pb, Ni, Cd	0 to 15, 15 to 30 cm depths on 20% of the sampling sites	4.65	3.71
Potassium	0 to 15, 15 to 30, 30 to 60, and 60 to 90 cm depths	3.32, 4.51	
Sulphate	0 to 15, 15 to 30, 30 to 60 and 60 to 90 cm depths	4.48	
Total nitrogen	0 to 15, 15 to 30 cm depths	3.622, 3.624	3.621, 3.623
Total carbon[c]	0 to 15, 15 to 30 cm depths	3.611	3.621, 3.613
Mechanical analyses	All depths sampled	2.11 or	2.21
1/3 and 15 bar moisture content[3]	0 to 15, 15 to 30 cm depths	2.431	
Modulus of rupture	0 to 15, 15 to 30 cm depths	Methods of soil analyses, Part 1, Agronomy No. 9, Amer. Soc. of Agronomy	

Source: Soil Quality Criteria Subcommittee (1981)

[a] McKeague, J.A. 1978. Manual on Soil Sampling and Methods of Analysis, Canadian Society of Soil Science, Ottawa, Canada.

[b] Not required in areas where the baseline characterzation study indicates that salinity and sodicity could not be a problem.

[c] Derelict lands only.

Table 14.13. Total depth and intervals that should be sampled in disturbed areas, in Alberta.

Plains cm	Boreal Forest cm	Eastern Slopes cm
0 to 15	0 to 15	0 to 15
15 to 30	15 to 30	15 to 30
30 to 60	30 to 60	30 to 60
60 to 90	60 to 90	
90 to 150	90 to 150	
150 to 200	150 to 200	

Source: Soil Quality Criteria Subcommittee (1981)

overlies a buffer between the solum and infertile or toxic spoil. Suggested thickness of these reconstructed soil layers or profile horizons are shown in Table 14.14. The chemical and physical characteristics of the topsoil, subsoil, and spoil required for use in reclamation for the Plains region are shown respectively in Tables 14.15, 14.16, and 14.17.

The recommendations of the SQCS identify three areas of weakness:

1. biological soil criteria must be identified and quantified through ongoing and future research;
2. physical property measurements capable of predicting and quantifying soil crusting and compaction must be identified; and
3. a clear definition of equal soil capability must be developed.

They also recommended the expansion of research to address specific problems and the potential of fly and bottom ash in reclamation. Lastly they recommend that documentation of the benefits of topsoil salvage and reclamation would facilitate support of the goal of soil quality preservation.

During the Criteria Workshop discussion it was evident several issues were not well defined in the document, including:

1. Soil orgainic matter quality is not assessed in the criteria as total organic matter or organic carbon only were measured; naturally evolved soil humus would be substantially different from peat and sewage organic ammendments in their soil fertility, soil quality, and soil stability properties.
2. Solum and buffer depths are based on limited empirical data; ongoing experiments at the Vesta and Highvale coal mines in the central plains region and at Syncrude in the northern forested region should help to alleviate this information gap.
3. Long term stability and pedogenesis of reconstructed profiles, have not been assessed; particularly crucial for

Table 14.4. Suggested limits of the three defined depths (cm) of soil materials used in soil reconstruction in Alberta.

Soil material	Good	Fair	Poor	Unsuitable
A. Topsoil	>15	5 to 15	<5	0
B. Subsoil	>100	60 to 100	<60	0
C. Buffer	>180	90 to 180	<90	0

Source: Soil Quality Criteria Subcommittee (1981)

Note: Topsoil is defined as the surface "A" horizons of the soil profile.

Subsoil is defined as the "B" horizon(s) and the upper portion of the parent material to a depth of 1.15 m.

Buffer is defined as that material between the root zone and bedrock or resource or unsuitable material that has properties such that it may be used to maintain the quality of the replaced root zone (topsoil and subsoil).

Table 14.15. Criteria for evaluating suitability of topsoil for revegetation in the Plains Region, in Alberta.

Rating/Property	Good	Fair	Poor	Unsuitable
Reaction (pH)	6.5 to 7.5	5.5 to 6.4 and 7.6 to 8.4	4.5 to 5.4 and 8.5 to 9.0	<4.5 and >9.0
Salinity (E.C.) (mS/cm)	<2	2 to 4	4 to 8	>8
Sodicity (SAR)	<4	4 to 8	8 to 12	>12
Saturation (%)	30 to 60	20 to 30, 60 to 80	15 to 20, 80 to 120	<15 and >120
Stoniness class	S0, S1	S2	S3, S4	S5
Texture	FSL, VFSL, L, SL, SiL	CL, SCL, SiCL	LS, SiC C[a], S, HC[b]	
Moist Consistency	Very friable, Friable	Loose	Firm, Very firm	Extremely firm
Organic carbon (%)	>2	1 to 2	<1	
Modulus of Rupture (bars)[c]	<1.0	1.0 to 2.5	2.5 to 5.0	>5.0
$CaCO_3$ Equivalent (%)	<2	2 to 20	20 to 70	>70

Source: Soil Quality Criteria Subcommittee (1981)

[a] C = May be upgraded to fair or good in some arid areas.

[b] HC = May be upgraded to fair or good in some arid areas.

[c] Modulus of Rupture (bars) = Tentative limits only pending further research.

Table 14.16. Criteria for evaluating suitability of subsoil material for revegetation in the Plains Region, in Alberta.

Rating/Property	Good	Fair	Poor	Unsuitable
Reaction (pH)	6.5 to 7.5	5.5 to 6.4 and 7.6 to 8.5	4.5 to 5.4 and 8.6 to 9.0	<4.5 and >9.0
Salinity (E.C.) (mS/cm)	<3	3 to 5	5 to 10	>10
Sodicity (SAR)	<4	4 to 8	8 to 12	>12
Saturation (%)	30 to 60	20 to 30, 60 to 80	15 to 20, 80 to 120	<15 and >120
Stone content (% Vol)	<3	3 to 25	25 to 50	>50
Texture	FSL, VFSL, L, SiL, SL	CL, SCL, SiCL	S, LS, SiC, C, HC	Bedrock
Moist Consistency	Very friable, Friable	Loose, Firm	Very form	Extremely firm
Gypsum $CaCO_3$ Equivalent (%)	The suitability criteria for sodicity (SAR) may be altered by the presence of high levels of either lime ($CaCO_3$) or gypsum ($CaSO_4$) in excess of other soluble salts. Consideration should be given to the salvage of calcareous or gypsiferous soil materials as they are useful in the amelioration of sodic soil materials.			

Source: Soil Quality Criteria Subcommittee (1981)

Table 14.17. Criteria for evaluating the suitability of buffer zone material for revegetation in the Plains Region, in Alberta.

Rating/Property	Good	Fair	Poor	Unsuitable
Reaction (pH)	6.0 to 8.0	5.5 to 5.9 and 8.0 to 8.6	4.5 to 5.4 and 8.6 to 9.0	<4.5 and >9.0
Salinity (E.C.) (mS/cm)	<4	4 to 8	8 to 12	>12
Sodicity (SAR)	<4	4 to 8	8 to 20	>20
Saturation (%)	30 to 60	20 to 30,	<20, 80 to 150	>150
Texture	FSL, VFSL, LS, L, SL, SiL	CL, SCL, SiCL, SiC, C	S, HC	Bedrock
Moist Consistency	Very friable, Friable, Firm	Loose, Very firm	Extremely Firm	Hardrock

Source: Soil Quality Criteria Subcommittee (1981)

example is the stability and pedogenesis of soil organic amendments.

In conclusion, the initial studies suggest that it is feasible and useful to develop such a reclamation suitability system, however considerable work is required to extend this beyond the site specific, productivity inventory type of study, such as those presented here. The two generalized ratings or quality type of studies noted here also require considerable work to expand their scope and improve the data bases from which they are derived. As previously discussed, the effect of handling and storage on productivity, and detailed approaches to increasing productivity and stability by amendments have to be included in the reclamation suitability system. Such a system, properly and fully developed, would provide a more holistic basis for maximizing the benefits to be derived from resource utilization at minimum economic cost.

14.1 SUMMARY

Rating systems must consider chemical, physical, and biological properties and encompass the utilization of amendments. The rating system must have the capability to assess the natural ecosystem, the effects of disturbance and alternate use, and ecosystem rehabilitation. Use of the system must result in the development of a soil of equal or better capability than the original soil, having long term self-sustaining properties.

Most systems in use today have been developed for undisturbed, primarily mineral soils. However, several rating systems have recently been developed for mined soils. Numerous criteria may be used; not all are relevant to a specific soil and one specific property may be critical to a predictive rating system.

A first approximation of a very complete and unique reclamation rating system has been published in Alberta. Criteria were developed for Plains, Mountains and Foothills, and North-east regions. Criteria for the Plains region are reviewed here.

Further research is needed to develop systems for general use, as opposed to site specific application.

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SECTION VI

AMENDMENTS TO ENHANCE

ADVERSE ROOTING ZONE PROPERTIES

15. SURFACE MANIPULATION

15.1 STUBBLE

In agricultural soils, stubble mulch farming has been used primarily to increase snow catch, reduce wind and water erosion, and to return biomass to the soil system. As such, stubble mulch has important implications regarding prevention of soil degradation by erosion and organic matter decomposition. In spoil reclamation it has traditionally been assumed that stubble mulch will have similar beneficial effects. Considerable research on the effect of stubble on moisture conservation, and wind and water erosion has been undertaken in agricultural soils, but very little research has been carried out on spoils.

Schuman et al. (1980) compared small grain stubble and crimped straw as mulch treatments on reclaimed land. In in situ experiments in Wyoming, they found cooler night-time and warmer day-time temperatures in the crimped straw (Table 15.1), and decreased moisture storage compared to the stubble (Table 15.2). The small grain stubble was markedly cheaper than the crimped straw (Table 15.3). They reported that stubble produced a more porous soil, decreased evaporation, and increased snow catchment, although they did not present data for these effects. They attributed the increased moisture storage primarily to increased infiltration.

15.2 DEEP AND SHALLOW CULTIVATION

Terminology regarding many of the cultural methods is not standarized. In the soils literature, the terms chiseling and subsoiling are more common than ripping. The Canadian definition describes chiselling or subsoiling as: "Subsoiling....The breaking of compact subsoils, without inverting them, with a special knifelike instrument (chisel), which is pulled through the soil usually at depths of 30 to 60 cm (12 to 24 inches) and spacings of 60 to 150 cm (2 to 5 ft)" (Canada Department of Agriculture 1976:37).

The West Germans also differentiate between deep loosening and deep ploughing in terms of objective. In the former, the objective is

Table 15.1. Average weekly daytime and nighttime soil temperatures at the 2.5 cm soil depth under the stubble and crimped straw treatments in an experimental spoil site in Wyoming.

	°C			
	Average Daytime Temperature		Average Nighttime Temperature	
Date	Stubble	Crimped Straw	Stubble	Crimped Straw
May 10 to May 13	7.6	8.0	3.6	3.3
May 14 to May 20	10.1	10.4	5.5	5.2
May 21 to May 27	13.7	14.4	8.6	8.4
May 29 to June 3	12.1	12.3	7.7	6.9
June 4 to June 10	14.9	16.5	10.2	10.1
June 11 to June 17	20.2	20.9	14.6	14.5
June 18 to June 24	22.3	22.9	16.9	16.4
June 25 to July 1	24.1	24.4	18.5	17.6

Source: Schuman et al. (1980).

Table 15.2. Effect of crimped straw and stubble treatments on overwinter soil moisture storage in an experimental spoil site in Wyoming.

	Percent Soil Moisture for Depth[a] of:			
Treatment	0 to 15 cm	15 to 30 cm	30 to 60 cm	Water in 60 cm Profile (50 cm)
Crimped straw	15.1	17.4	19.6	5.8
Stubble	17.1	18.5	19.7	6.1

Source: Adapted from Schuman et al. (1980).
[a] Each data point represents the average of 20 samples.

Table 15.3. Cost comparisons of crimped straw and stubble treatments for protection of soil and seedling establishment at two spoil locations in Wyoming.

Location	Cost of Crimped Straw (5 t/ha)	Cost of Planted Stubble
1[a]	$803/ha	$ 40/ha
2[b]	$618/ha	$148/ha

Source: Schuman et al. (1980).

[a] D. Gary Deverau, reclamation director, Northern Energy Resources Co., Glenrock Coal Co., Wyoming; millet stubble.

[b] Strat Murdock, environmental coordinator, Pathfinder Mines Corp., Shirley Basin Mine, Shirley Basin. Wyoming; barley stubble (certified seed used).

to break or loosen compact soil structure while in the latter the objective is to mix subsurface and surface horizons. Figure 15.1 illustrates this difference for the same implement. The Germans define deep loosening as the breaking up and lifting of an area of surface soil to a depth at least 40 cm, through use of a loosening instrument (Egglesman 1978).

Ploughing and cultivation achieve similar aeration and loosening effects to deep ploughing and subsoiling except that the former are confined to a shallow surface layer usually not exceeding 25 cm, and the effects of increased aeration are more intense in this layer. Experience has shown, that in Alberta's agricultural soils, aeration due to shallow ploughing has accelerated organic matter decomposition, contributing to significant soil deterioration. This problem can be avoided by deep subsoiling or chisel ploughing to achieve sufficient structural soil loosening and aeration without inducing intense biological decomposition from excessive aeration. Chiselling or subsoiling is also known to alter pedogenesis significantly and to increase: (1) infiltration to greater depth, (2) aeration at depth, (3) root penetration to greater depths, and (4) leaching.

In the Colstrip area of Montana, Sindelar et al. (1974) studied what they termed chiselling. In this study, a Graham Hoeme plough was used to break surface units to a depth of 20 to 30 cm and the treatment was, therefore, in actuality, shallow ploughing or cultivation. The treatment was compared with gouging and dozer basins. The gouging treatment produced the most plant cover and greatest vegetation yield. The authors also described the early experiments of Nichols on heavy clay soils in Montana where "ripping" to 30 to 35 cm soil depth, at 1.8 m spacing, resulted in significant increases in plant density and yield.

Sindelar et al. (1974) set up 12 plots to test the effects of ripping freshly topsoiled coal spoils to a depth of 1 m on the establishment of a broad mix of grasses, legumes, and shrubs. Plots were ripped at 1.5 or 2.5 m spacings in one or two directions. Meyn,

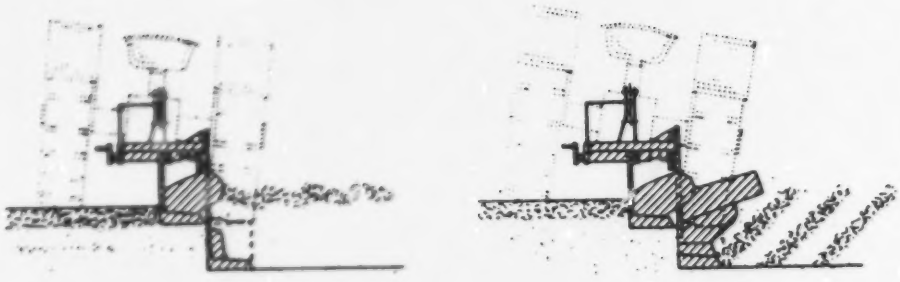

Figure 15.1. ROEWER two-layer plow used in West Germany: (a) for subsoil loosening; (b) for soil mix.

Source: Egglesman (1978)

Sundberg and Young (1976) noted that plant establishment on these plots was poor and that no differences among treatments were detected.

Sindelar et al. (1974) concluded that chiselling, ripping, cultivation, and other surface manipulations on spoils and reconstructed soil may be necessary as an initial treatment and as an alternative to other cultural methods because of spoil compaction. They also suggest such practices may be necessary on a continuing basis in reconstructed agricultural soils in the Plains region to minimize soil degradation.

Chiselling and other surface manipulations are especially relevant in arid and sodic soils in the Alberta Plains region where crusting, soil compaction, capillary uptake of salts, and low infiltration rates can cause surface water ponding and plant toxicity problems.

15.3 FURROWS

Furrows are soil ridges produced by surface manipulation. They can trap water, snow, and soil particles and also add to the surface roughness or surface drag (commonly measured as roughness length) which in turn reduces wind erosion (e.g., Monteith 1973:89; Rose 1966:62). Their major limitation is that they are usually ephemeral or short lived as the furrows tend to fill in after several years (e.g., Riley 1973; Figure 15.2).

Riley (1973) described a 10-year experiment on furrowed versus conventionally cultivated spoil in Ohio. Riley was particularly interested in changes in soil salt levels and soil moisture levels. Fines collected in the furrows (Figure 15.2), reportedly resulting in greater moisture retention than on ridges (although no data were presented). The increased infiltration and hypothesized leaching in the furrows compared to the ridges tended to lower cation and anion levels, especially Ca^{++}, Mg^{++}, Mn^{++}, Cu^{++}, and Zn^{++}. Most of the other metals and micronutrient levels showed less systematic changes (Tables 15.4 and 15.5). One would expect this ion depletion to lower soil pH; however soil pH tended to be higher on the cultivated area, and higher in the

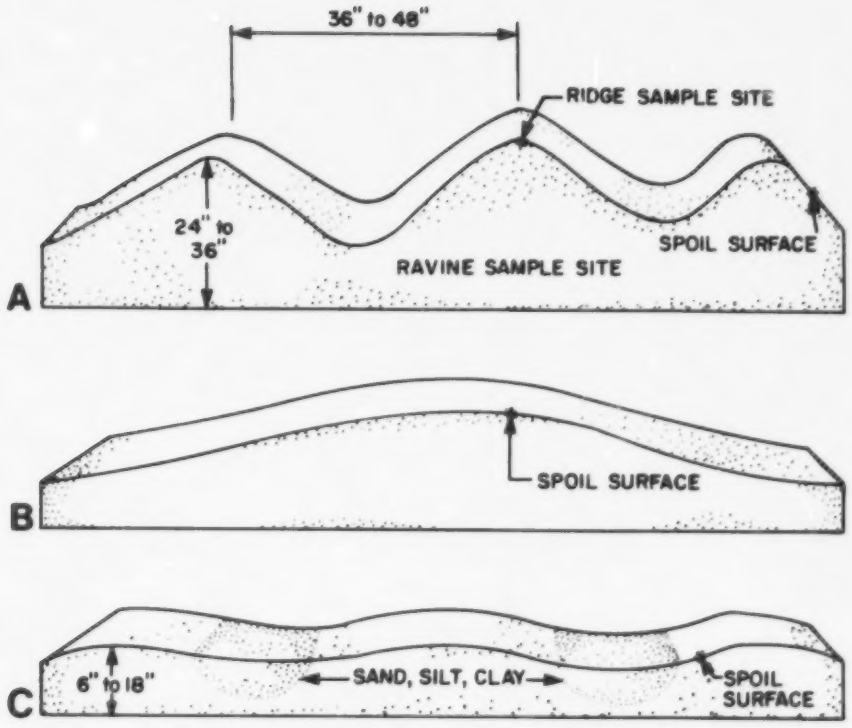

Figure 15.2. Furrow grading (A) versus conventional grading (B); (C) resulting topography four years after grading.

Source: Riley (1973a)

Table 15.4. Chemical variations by site after ten years of weathering in Ohio coal spoil.[a]

	Plot 1 (kg/ha)		Plot 2 (kg/ha)		Plot 3 (kg/ha)		Plot 4 (kg/ha)		Plot 5 (kg/ha)
	Ridge	Ravine	Ridge	Ravine	Ridge	Ravine	Ridge	Ravine	Smooth
T. Salts	448.4	224.2	1121.0	313.9	717.4	313.9	269.0	246.6	941.6
S as SO_4	224.2	153.6	313.9	237.7	283.6	185.0	153.6	112.1	230.9
Ca	248.9	123.3	311.6	168.2	195.1	100.9	235.4	325.1	311.6
Mg	67.3	58.3	80.7	56.1	100.9	62.8	114.3	105.4	84.1
NO_3	1.5	1.7	2.1	1.5	3.4	1.9	1.5	1.7	2.7
NH_3	51.8	40.4	46.0	43.7	47.1	44.8	43.7	56.1	50.5
P_2O_5	0.9	1.4	0.6	1.2	1.4	1.9	1.0	0.9	1.5
K_2O	39.2	29.2	72.9	44.8	53.8	49.3	39.2	107.6	34.8

Source: Adapted from Riley (1973)

a Summer samples.

Table 15.5. Micronutrient concentrations by site after ten years of weathering in Ohio coal spoil.

	Plot 1 (kg/ha)		Plot 2 (kg/ha)		Plot 3 (kg/ha)		Plot 4 (kg/ha)		Plot 5 (kg/ha)
	Ridge	Ravine	Ridge	Ravine	Ridge	Ravine	Ridge	Ravine	Smooth
Fe^{+++}	0.3	3.8	1.5	4.3	0.6	4.3	0.34	0.5	5.6
Mn^{++}	7.3	2.9	11.7	6.1	14.4	11.0	13.6	6.7	4.5
Cu^{++}	4.2	1.1	5.4	1.3	3.0	1.7	0.9	2.1	2.2
Zn^{++}	2.8	1.4	3.0	1.7	0.9	1.1	1.1	3.9	1.9
Al^{+++}	4.0	3.9	4.0	3.5	3.1	3.5	3.0	2.8	3.5
Cl^{-}	8.6	6.2	6.2	9.8	11.0	5.4	7.4	14.4	13.5
B^{+++}	0.40	0.38	0.4	0.39	0.46	0.43	0.44	0.5	0.4
Mo^{+6} (PPB)	151.3	168.2	168.2	196.2	140.1	196.2	196.2	168.2	168.2

Source: Adapted from Riley (1973)

furrows than in the ridges. Iron levels also increased in the furrows (Table 15.5).

Thus furrows in this situation provide a favoured vegetation microsite of enhanced available soil moisture, soil pH, and decreased salt toxicity level without substantial reductions in K and some micronutrient levels.

Meiman (1974) pointed out the utility and risks of contour trenching to control runoff. For example, failure of such trenches can actually cause more severe erosion than would normally occur on untrenched slopes. He also noted that contour furrowing (by plough) is preferable to contour trenching (by mechanical trencher) in most high elevation soils because of reduced costs and less risk of physical failure of the furrow walls. Contour furrows at 1 to 1.7 m intervals were effective in medium to fine textured soils.

Davidson (1974) found that furrowing on coal spoils in Pennsylvania had no discernible positive effect on establishment of grasses, survival of tree seedlings, or erosion.

Hodder (1977) described a form of furrows, which he termed off-set listering, consisting of alternately arranged elongated pits 15 cm deep and 1.2 m long, although he did not report further on these furrows.

15.4 GOUGING AND DOZER BASINS

Gouging and dozer basins are very prevalent surface manipulation techniques. Unfortunately, there is no uniform or standard definition of such techniques or features. Hodder (1977), Sindelar et al. (1974) and Sindelar, Hodder and Majerus (1973) describe gouging as depressions 15 to 25 cm deep, 35 to 45 cm across, and 60 to 120 m long and dozer basins as 60 to 120 cm deep, 6 to 8 m wide, and 4 to 6 m long.

In the Colstrip, Montana area, Sindelar, Hodder and Majerus (1973) compared chiseling, gouging, and dozer basins particularly with respect to their effect on plant available moisture (Tables 15.6 and 15.7). The gouged plots stored significantly more soil moisture in the

Table 15.6. Average soil moisture block conductivity[a] (μa) at five depths for three surface manipulation treatments during the period 5/12/72 to 11/2/72 at Rosebud Mine, Colstrip, Montana.

Treatment	5.08 cm	0.3 m	0.6 m	0.9 m	1.2 m	$\bar{x}$
Dozer	45.5 a	50.3 a	58.8 a	74.6 a	86.4 a	63.12 a
Chisel	42.6 a	42.5 b	61.7 a	73.2 a	90.6 a	62.12 a
Gouge	48.0 b	57.4 c	79.1 b	93.2 b	115.7 b	78.68 b

Source: Adapted from Sindelar, Hodder and Majerus (1973)

Note: Figures in each column followed by the same letter are not significantly different at the 95% level of significance.

[a] Increased conductivity indicates increased soil moisture content.

Table 15.7. Number of days during study period in which soil moisture dropped below the wilting point[a] for plants at Rosebud Mine, Colstrip, Montana.

	0	0.3 m	0.6 m	0.9 m	1.2 m
Chisel	48	71	51	20	0
Dozer	47	19	46	0	0
Gouge	46	6	0	0	0

Source: Adapted from Sindelar, Hodder and Majerus (1973)

[a] The wilting point is considered to be approximately 15 atmospheres.

upper 1.2 m than the other treatments. Dozer basins contained more moisture in the upper 0.3 m when compared to the deep chiselled plots.

In what they termed "micro-watersheds" in Montana, North Dakota, and Wyoming, Dollhopf, Jensen and Hodder (1977) studied the effects of spoil topsoiling in combination with chiselling, dozer basins, and gouging on infiltration, runoff, and the chemistry of runoff waters. Infiltration experiments showed that the effect of surface treatment was strongly influenced by the nature of underlying spoil. In non-swelling clays, chiselling with topsoil present provided rapid sustained infiltration, followed by chiselling of spoil alone and finally the dozer basin treatment (Figure 15.3). In spoils of swelling smectite clays, infiltration rapidly declined upon wetting, obscuring any treatment effects (Figure 15.4). However, in a third spoil plot of swelling smectite clays, slightly different trends were evident. Due to large soil cracks, chiselling accelerated infiltration although as the cracks began to close infiltration decreased slowly in the chiselled plots (Figure 15.5).

Dollhopf, Jensen and Hodder (1977) also studied how the above treatments stored and retained moisture and soil. Through observation over one year they also estimated the limited life expectancy of these surface treatments due to sedimentation. As shown in Table 15.8, plots which were gouged and topsoiled had the least erosion. The large proportion of surface area in the gouged depressions (Table 15.9) limited gully formation and thus gully erosion. Total runoff (shown in Table 15.10), however, was more likely controlled by total water holding capacity. Measured rates of runoff were always least from the dozer basins as they had the largest capacity (Table 15.11). Topsoiling consistently reduced runoff, particularly in gouged and chiselled treatments.

The authors could not discern differences in chemistry of surface runoff water among treatments. They point out, however, that data were calculated on a concentration basis and must be multiplied by runoff volume to give actual levels of nutrient load leaving the plots.

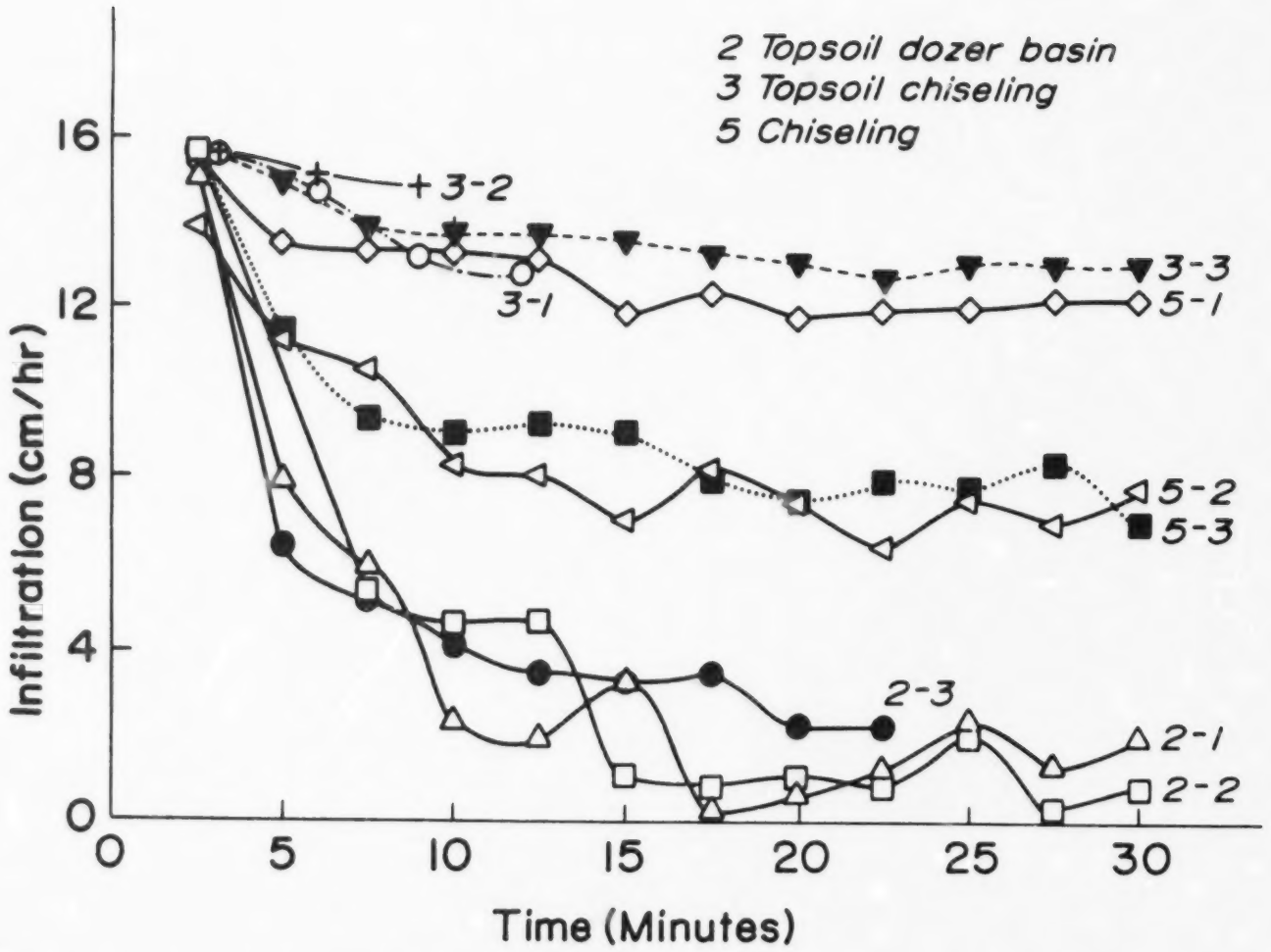

Figure 15.3. Infiltration rates as a function of three surface manipulation treatments at the Colstrip Demonstration Area during August 1975. The first identification digit represents treatment while the second denotes replication.

Source: Dollhopf, Jensen and Hodder (1977)

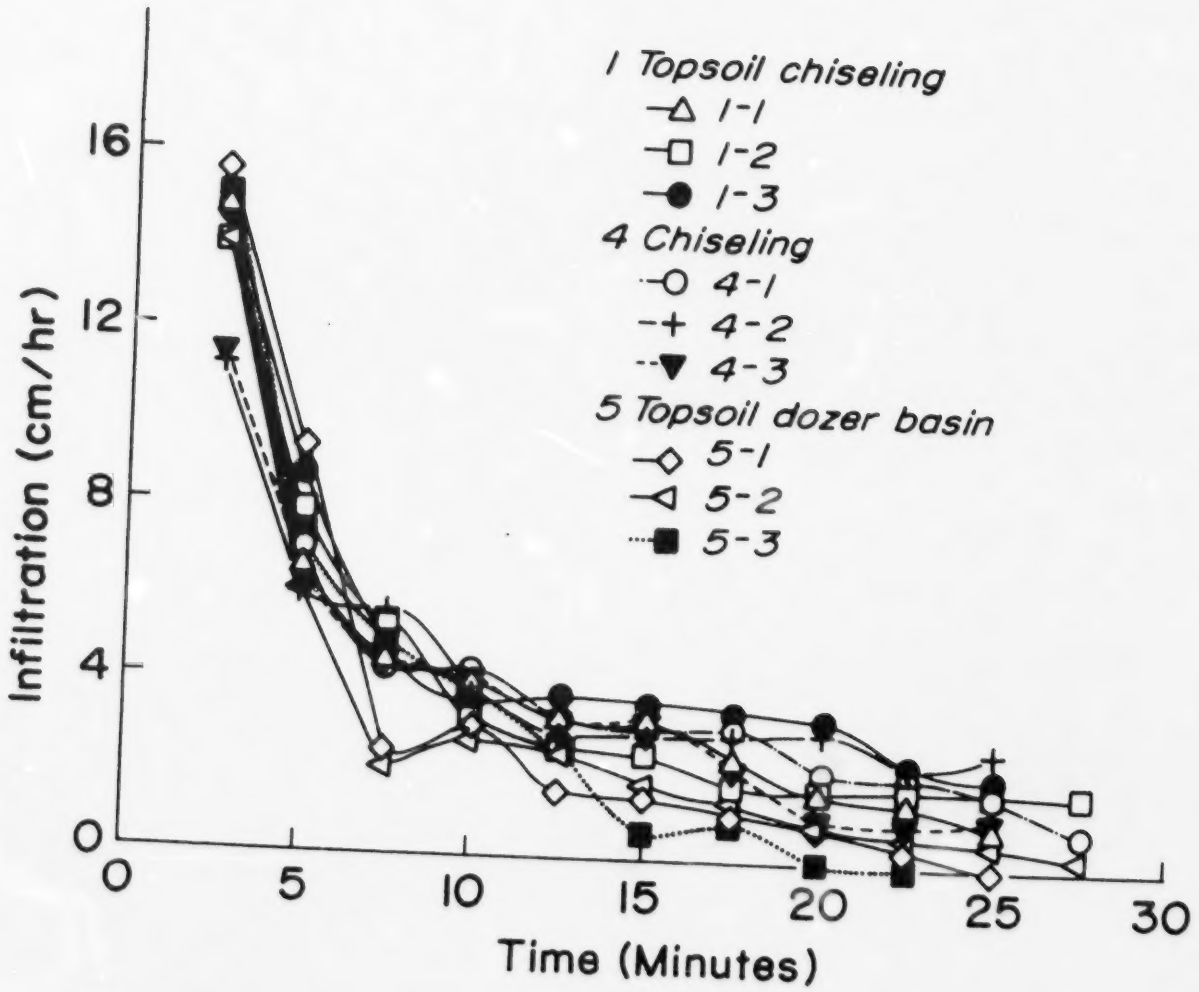

Figure 15.4 Infiltration rates as a function of three surface manipulation treatments at the Savage Demonstration Area during August 1975. The first identification digit represents treatment while the second denotes replication.

Source: Dollhopf, Jensen and Hodder (1977)

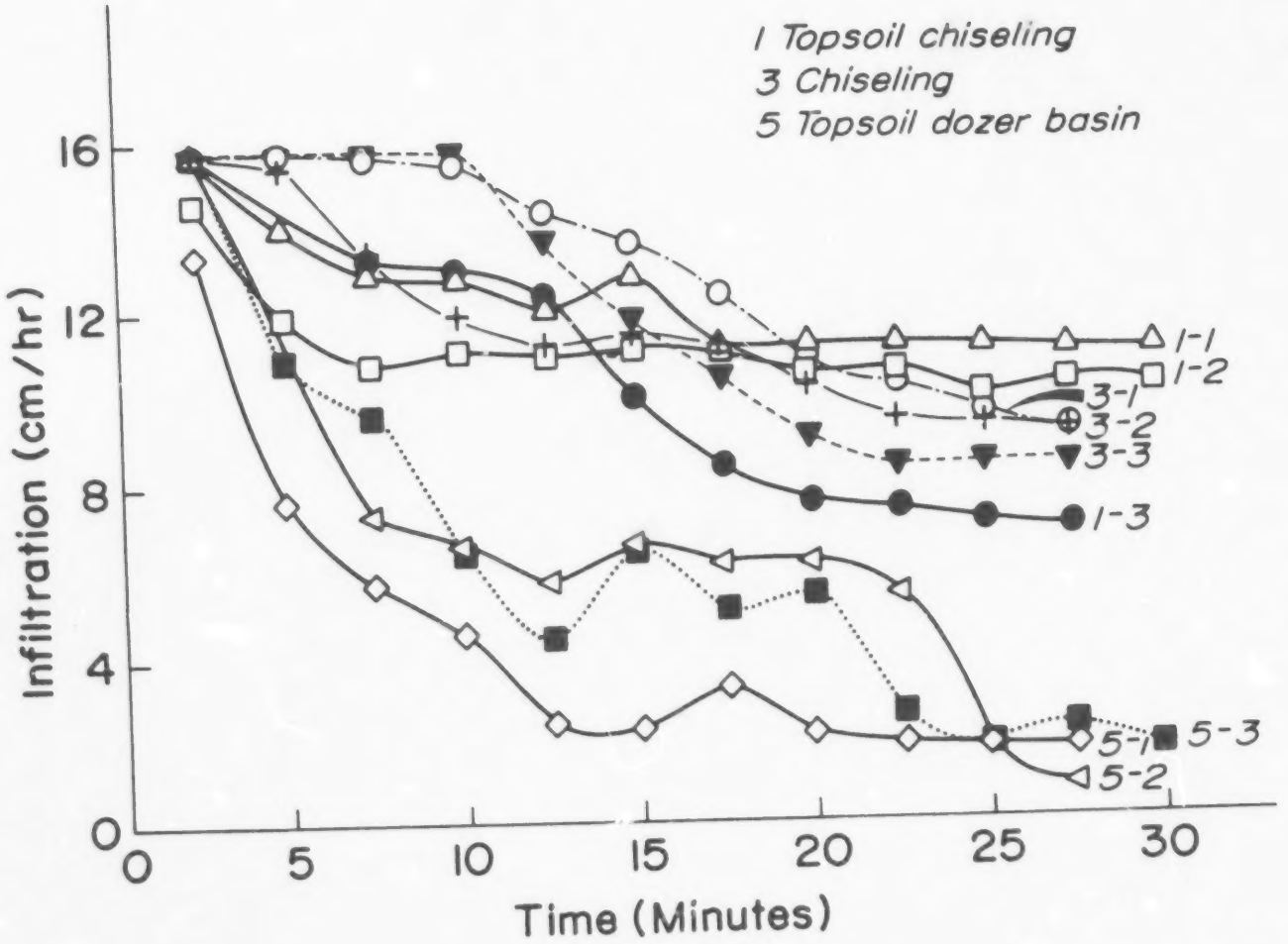

Figure 15.5 Infiltration rates as a function of three surface manipulation treatments at the Beulah Demonstration Area during August 1975. The first identification digit represents treatment while the second denotes replication.

Source: Dollhopf, Jensen and Hodder (1977)

Table 15.8. Volume of individual gullies for the Savage and Colstrip experimental sites in Montana.

Watershed treatment	Total gully volume (m^3)
Savage demonstration	
Non-topsoil gouged	14.00
Topsoil gouged	6.85
Non-topsoil chiseled	36.50
Topsoil chiseled	20.70
Topsoil dozer basins	2.70
Colstrip demonstration	
Non-topsoil gouged	9.7
Topsoil gouged	1.26
Non-topsoil chiseled	6.6
Topsoil chiseled	5.70
Topsoil dozer basins	None

Source: Adapted from Dollhopf, Jensen and Hodder (1977)

Table 15.9. Aerial extent of depressions created by surface manipulation techniques at the Colstrip, Savage, and Beulah Demonstration Areas, in Montana.

Treatment	Depressions per unit area (ha)
Colstrip demonstration	
Topsoil gouged	7815
Non-topsoil gouged	4775
Topsoil dozer basin	1220
Savage demonstration	
Topsoil gouged	6230
Non-topsoil gouged	5646
Topsoil dozer basin	825
Beulah demonstration	
Topsoil gouged	5325
Non-topsoil gouged	4025
Topsoil dozer basin	375

Source: Dollhopf, Jensen and Hodder (1977)

Table 15.10. Surface runoff events which have occurred on the demonstration watersheds in Montana, from inception to June 15, 1976. Total runoff would be equivalent to the surface area of the watershed x water depth.

Demonstration Area	Date of Runoff Event	Watershed Treatment	Total Event Runoff (surface cm)
Savage	Jan. 17, 1976	Non-topsoil chiseled	0
		Topsoil chiseled	0
		Non-topsoil gouged	3.1
		Topsoil gouged	0
		Topsoil dozer basin	0
	May 25, 1976	Non-topsoil chiseled	0.86
		Topsoil chiseled	0.22
		Non-topsoil gouged	1.35
		Topsoil gouged	0.34
		Topsoil dozer basin	0.13
	June 2, 1976	Non-topsoil chiseled	2.27
		Topsoil chiseled	1.83
		Non-topsoil gouged	2.20
		Topsoil gouged	ND [a]
		Topsoil dozer basin	0.55
	June 7, 1976	Non-topsoil chiseled	2.41
		Topsoil chiseled	1.26
		Non-topsoil gouged	2.45
		Topsoil gouged	ND
		Topsoil dozer basin	0.23
	June 11, 1976	Non-topsoil chiseled	0
		Topsoil chiseled	0.49
		Non-topsoil gouged	0
		Topsoil gouged	ND
		Topsoil dozer basin	0
Colstrip	June 6, 1976	Non-topsoil chise'ed	1.26
		Topsoil chiseled	0.64
		Non-topsoil gouged	0.94
		Topsoil gouged	0.62
		Topsoil dozen basin	0.43
	June 11, 1976	Non-topsoil chiseled	1.40
		Topsoil chiseled	0.32
		Non-topsoil gouged	1.40
		Topsoil gouged	1.36
		Topsoil dozer basin	0.29
Beulah	May 16, 1976	Non-topsoil chiseled	8.5
		Topsoil chiseled	0
		Non-topsoil gouged	2.4
		Topsoil gouged	0
		Topsoil dozer basin	0

Source: Adapted from Dollhopf, Jensen and Hodder (1977)

[a] ND = malfunction

Table 15.11. The average water depression capacity on mine spoil watersheds as a function of five treatments at the Colstrip, Savage, and Beulah Demonstration Areas in Montana.

Treatments	Surface water holding capacity (L/ha x 10^3)		
	Colstrip	Savage	Beulah
Before sedimentation[a]			
Non-topsoil chiseled	ND[b]	ND	122.2
Topsoil chiseled	ND	ND	176.4
Non-topsoil gouged	24.7	38.2	133.8
Topsoil gouged	68.2	25.6	189.5
Topsoil dozer basin	522.9	128.8	ND
July, 1975			
Non-topsoil chiseled	186.5	37.9	ND
Topsoil chiseled	81.4	0.0	ND
Non-topsoil gouged	11.3	0.7	ND
Topsoil gouged	52.8	0.0	ND
Topsoil dozer basin	516.4	125.3	ND
June, 1976			
Non-topsoil chiseled	29.1	0.4	27.2
Topsoil chiseled	3.7	0.3	30.9
Non-topsoil gouged	1.4	5.1	113.5
Topsoil gouged	7.4	2.2	198.7
Topsoil dozer basin	295.8	207.9	ND

Source: Dollhopf, Jensen and Hodder (1977)

[a] The Colstrip and Savage Demonstration Areas were measured during April, 1975, and the Beulah Area in August, 1975.

[b] Data not collected.

Those treatments which have the least runoff (dozer basins, topsoiled plots) will have the least total nutrient loss.

Small effects of topsoiling and surface manipulation on soil moisture status were detected. At the Colstrip, Montana site, topsoiling tended to increase the soil moisture level by about 5% on average (Figure 15.6). The most marked treatment effects for all sites were evident during the spring recharge between the February and May measurements (Figure 15.6, Table 15.12). Treatment effects were more evident at the Colstrip site where the parent material was sandstone. At the Savage and Beulah sites, the smectite clay spoil tended to obscure the treatment effects as shown by soil moisture levels. The authors concluded that effects on recharge were significant and different from the Colstrip site in that recharge from all chiselled and gouging treatments exceeded that for dozer basins (Table 15.12). Surface treatments will control soil moisture through factors of depression volume and stability, soil texture and compaction, and slope. The authors noted that an optimum combination of sufficient topsoil and long life using large capacity depressions constructed in permeable soil will result in maximum water recharge.

The maximum life expectancy of the individual surface treatments varied among sites but was probably less than five years, suggesting the vegetation must be by then sufficiently established to withstand the same level of moisture stress which would be expected on relatively smooth soil surfaces (Table 15.13).

DePuit, Willmuth and Coenenberg (1977) reported soil bulk density data for spoil pastures in the Colstrip, Montana region (Table 15.14). Bulk density in the dozer basins was not significantly different from that in the other plots. These data tended to be slightly lower than those reported for similar situations at and near the Rosebud Mine (up to 2.0 gm/cm^3 in the same area (Sindelar et al. 1974; Table 15.15). Note that the mean spoil bulk density at the Rosebud Mine is markedly higher than that of the adjacent natural soils (Table 15.15). Since plant roots may not penetrate soil bulk densities above 1.75 g/cm^3 in sandy soils and 1.46 g/cm^3 in heavy clays (Veihmeyer

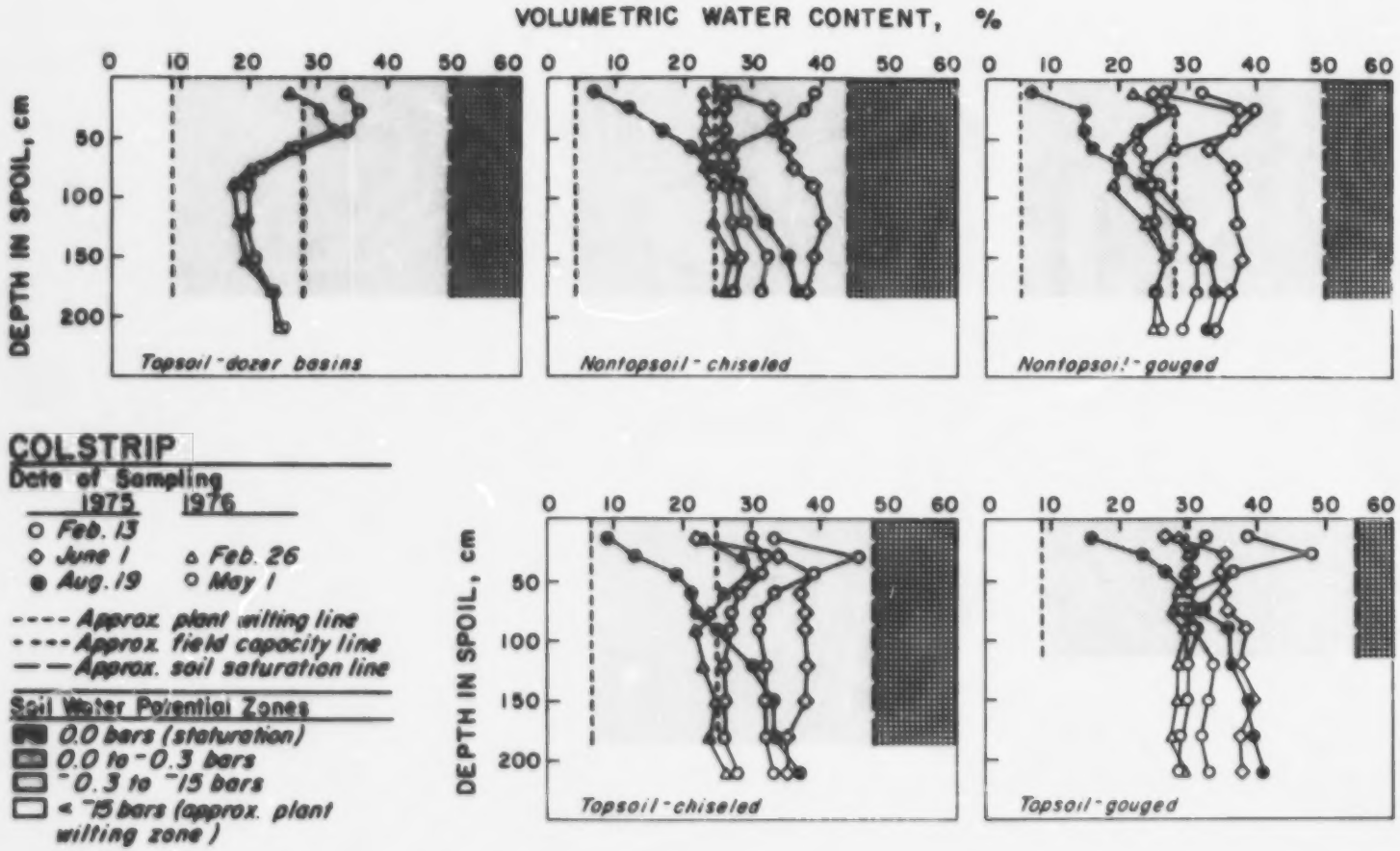

Figure 15.6. Soil profile water distribution over time as a function of surface manipulation treatments at the Colstrip demonstration.

Source: Dollhopf, Jensen and Hodder (1977)

Table 15.12. Spring recharge between February and May, 1976, at the Colstrip, Savage, and Beulah sites in Montana.

Treatment or Surface manipulation	Recharge in cm water[a]		
	1	2	3
Topsoil dozer basins	13.0	3.5	0.0
Topsoil chiseled	8.0	5.0	5.2
Non-topsoil chiseled	7.5	4.5	8.0
Topsoil gouged	5.0	8.0	5.5
Non-topsoil gouged	4.5	6.5	6.5

Source: Dollhopf, Jensen and Hodder (1977)

[a] Sites: 1. Colstrip = sandstone
2. Savage = smectite clay
3. Beulah = smectite clay

Table 15.13. Estimated rate of sedimentation and life expectancy of five surface manipulation treatments constructed at the Colstrip, Savage, and Beulah Demonstration Areas, in Montana.

Treatment	Detention capacity Decrease per year (%)	Minimum effective life of depression (years)
Colstrip demonstration		
Non-topsoil chiseled	92	< 2
Topsoil chiseled	85	< 2
Non-topsoil gouged	96	< 2
Topsoil gouged	94	< 2
Topsoil dozer basin	47	> 5
Savage demonstration		
Non-topsoil chiseled	100	< 1
Topsoil chiseled	100	< 1
Non-topsoil gouged	100	< 1
Topsoil gouged	100	< 1
Topsoil dozer basin	ND[a]	ND
Beulah demonstration		
Non-topsoil chiseled	85	< 2
Topsoil chiseled	90	< 2
Non-topsoil gouged	17	> 5
Topsoil gouged	0	> 5
Topsoil dozer basin	ND	ND

Source: Dollhopf, Jensen and Hodder (1977)

[a] Missing data.

Table 15.14. Baseline soil bulk density (an index of compaction), at 15 cm soil depth, of selected physiographic units within the six experimental spoils pastures, Colstrip, Montana, 1975. (Data are expressed as g/cm^3).

Pasture No.	Physiographic Unit						
	Average	Fence	Dozer basins	Near stock watering tanks	Ridge	Central swale	Major slope E,W,N,S
1	1.26	1.25	1.25	1.29	1.26	ND	ND
2	1.19	1.18	1.14	1.17	ND	1.24	1.23 E
3	1.32	ND[a]	ND	ND	1.38	ND	1.26 N
4	1.29	1.34	ND	1.25	1.29	1.28	ND
5	1.26	ND	ND	ND	1.25	ND	1.26 N 1.28 S
6	1.30	ND	ND	ND	1.28	1.28	1.25 N 1.39 SE
Average	1.27	1.26	1.20	1.24	1.29	1.26	1.28

Source: DePuit, Willmuth and Coenenberg (1977)

[a] ND indicates that the given physiographic unit was not sampled.

Table 15.15. Average bulk density of soil sampled at three depths in and near the Rosebud mine in the Colstrip area of Montana.

Type			0 to 15 cm	15 to 30 cm	30 to 45 cm	$\bar{x}$
1	1973	Native rangeland (unfertilized, ungrazed)	1.26	1.45	1.54	1.42
1	1973	Native rangeland (fertilized[a], ungrazed)	1.24	1.39	1.44	1.42
1	1972	Native rangeland (unfertilized, grazed)	1.48	1.58	1.47	1.51
2	1973	Old spoils	1.45	1.87	1.91	1.74
3	1973	Plant community development	1.27	1.77	1.79	1.61
	1972		1.72	1.73	1.89	1.78
4	1973	Dryland pasture	1.52	1.76	1.74	1.67
	1972		1.62	2.33	1.74	1.90
5	1973	Topsoiling gradient	1.23	1.50	1.58	1.44
	1972		1.33	1.57	1.51	1.47
6	1973	Surface manipulation (gouging)	1.49	1.76	1.74	1.66
7	1973	Temporary stabilization				
		(Barley)	1.36	1.61	1.67	1.55
		(9090)	1.36	1.51	1.60	1.49
7	1973	Temporary stabilization				
		(Rape)	1.94	1.87	1.86	1.89
		(Rye)	1.72	1.72	1.83	1.76
		(Sudan)	1.55	1.87	1.67	1.70
		(Sorghum)	1.46	1.85	1.93	1.75

Source: Sindelar et al. (1974)

[a] Fertilized with 90 kg/ha N and 113 kg/ha P on March 27, 1973.

LEGEND: Type

1 Native rangeland: A western wheatgrass-broom snakeweed rangetype, ungrazed for several years, with both fertilized and control plots sampled.

2 Old spoils: Leveled raw spoils abandoned in 1930 or 1932 and naturally invaded by grasses, shrubs, legumes, and trees. Never seeded or fertilized.

3 Plant community development study: Topsoiled spoils seeded with grasses, shrubs, and legumes in May, 1972, and fertilized annually.

4 Dryland pasture mixture study: Raw spoils seeded with a pasture mixture in 1971 and fertilized annually.

5 Topsoil gradient study: Topsoiled spoils seeded with Lincoln smooth bromegrass and fourwing saltbush in May, 1972, and fertilized annually.

6 Surface manipulation study: Raw spoils seeded with a mixture of grasses, shrubs, and legumes in December, 1971, and fertilized annually. The gouging treatment was sampled.

7 Temporary stabilization: Topsoiled spoils seeded with barley and winter-graze 9090 in spring, 1973, and fertilized once.

and Hendrickson 1948), the effect of surface manipulation on bulk density is crucial. Topsoiling spoil at the Rosebud Mine significantly lowered average bulk density while gouging tended to have a lesser effect and possibly increased bulk density (Table 15.15). Temporary stabilization resulted in very high bulk densities. It should also be pointed out that conflicts may arise between objectives when choosing or planning surface manipulation. For example, gouging may be desired to increase soil moisture infiltration in an arid climate; however, if the spoil is highly sodic as is quite common in such arid climates, gouging may increase soil compaction to detrimental levels (Sindelar et al. 1974). In this situation, a compromise or combination of techniques is required to enhance soil moisture status and lower soil bulk density.

15.5 CONDENSATION AND MOISTURE TRAPS

Hodder (1970,1973,1977) described one of the common techniques for alleviating plant moisture deficits in arid continental type climates which is a combination of surface manipulation, a basin, and plastic mulching. Condensation traps consist of individual circular basins with a centre peak, covered with either a clear or opaque plastic liner. An air gap between liner and basin walls causes condensation on the underside of the liner, supplying moisture to the plant in the centre peak (Figure 15.7). Table 15.16 illustrates how effective the traps are in increasing moisture supply. In this experiment the clear liner consistently collected more moisture than the opaque black liner. Over the duration of the experiment, representing 36 days of collection, the clear liner collected 8.13 L while the black liner collected only 4.42 L or 54% of that collected by the clear liner. Hodder did not discuss basin dimensions or construction.

Aldon and Springfield (1975,1977) in north-eastern New Mexico, studied the effectiveness of various surface film treatments on survival of Caragana arborescens and Atriplex canescens planted in basins. The surface film treatments included black polyethylene, ground paraffin, silicone spray, straw, and portland cement. Many of the treatments

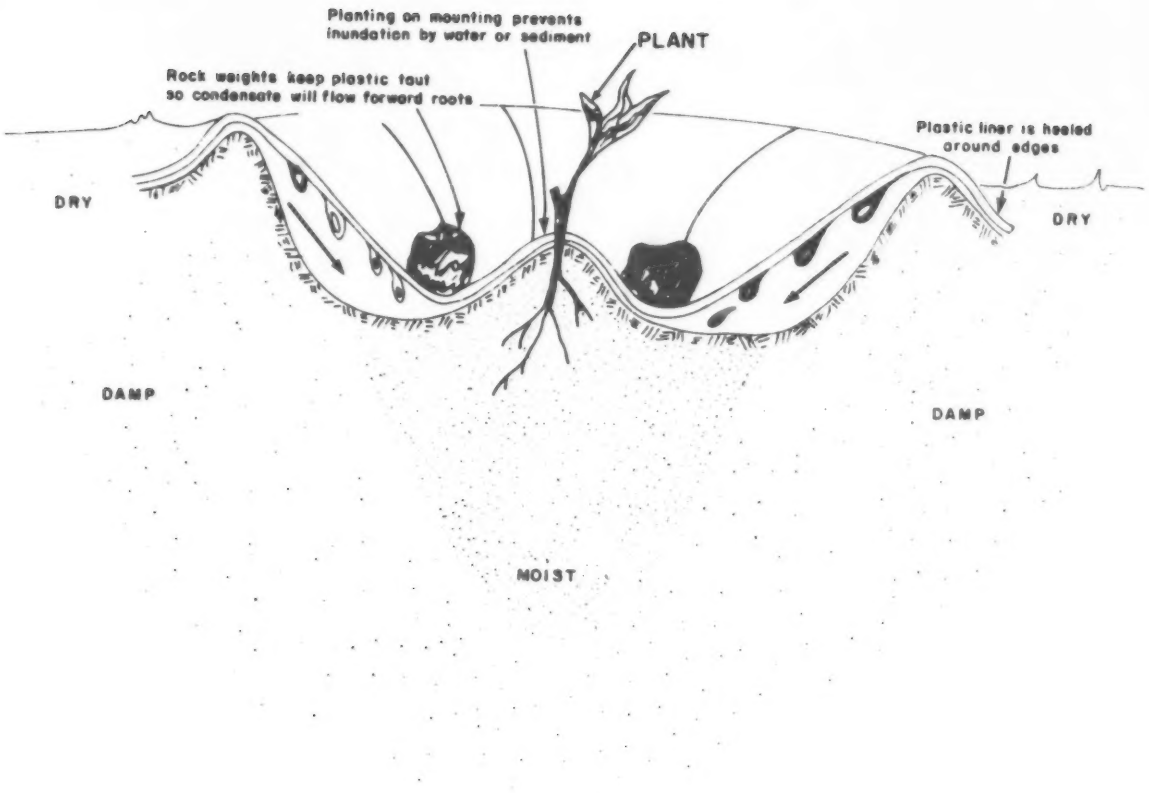

Figure 15.7. Sample condensation trap for dryland planting.

Source: Hodde (1977)

Table 15.16. Temperature and moisture data from condensation traps at Logan, Montana.

Outside Basin Temperature (°C) Min.	Outside Basin Temperature (°C) Max.	Date of Reading	Inside Basin Temperature (°C)[a] Min.	Inside Basin Temperature (°C)[a] Max.	Time Period Hours	Time Period Days	Plastic Colour	Condensate Collected (mL)
13.9	31.1	69 7 25	ND	ND	21½	1	Clear	73
		69 7 25	ND	ND	21½	1	Black	20
10.6	29.4	69 7 26	10.0	42.2	24	1	Clear	63
		69 7 26	11.1	39.4	24	1	Black	16
13.3	35.0	69 7 29	8.9	48.8	72	3	Clear	403
		69 7 29	10.0	43.3	72	3	Black	144
12.8	31.7	69 7 30	8.3	47.7	24	1	Clear	88
		69 7 30	7.8	38.8	24	1	Black	16
13.3	31.7	69 8 1	9.4	48.3	44	2	Clear	181
		69 8 1	10.6	45.0	44	2	Black	84
5.6	37.8	69 8 15	6.7	56.6		7	Clear	1109
		69 8 15	5.0	50.0		7	Black	319
6.7	35.6	69 8 22	1.1	55.0		7	Clear	2011
		69 8 22	3.3	45.5		7	Black	1016
2.8	38.3	69 8 30	5.6	53.3		8	Clear	2142
		69 8 30	0.0	52.2		8	Black	1568
-0.6	33.3	69 9 5	-4.4	50.0		6	Clear	2062
		69 9 5	-5.6	43.3		6	Black	1242

Source: Adapted from Hodder (1977)

[a] Temperatures recorded on basin bottom in shade.

Note: Mean annual temperature, 8.05 °C; mean annual precipitation, 26.2 cm; elevation, 1229.9 m.

enhanced moisture retention, and in turn establishment although no data on soil moisture levels or temperature were reported. For one experiment, using ground paraffin and black polyethylene, a 120 cm water catchment area was created around Atriplex canescens transplants. The paraffin was applied at 0.004 kg/cm^2 and melted into the soil at 48.9°C forming a surface coating which repelled rain. Both treatments (paraffin and polyethylene) added an average of 2 cm more moisture to the plants than in the untreated plots over the 15 cm summer precipitation (Aldon and Springfield 1977).

In another experiment, silicon crusts were employed but if they were fractured, water repellancy was easily reduced. Although the paraffin crusts were easily disturbed, they gave better water repellance the the silicone, whether the paraffin crust was disturbed or not (Aldon and Springfield 1977).

15.6 SUMMARY

Very little research has been carried out on stubbling or crimped straw treatment of spoils. Limited information indicates that stubble is better than crimped straw in terms of enhanced physical soil properties.

Shallow cultivation provides more aeration to spoils and may result in increased decomposition of organic material. The soil quality may deteriorate. Chiselling and subsoiling (deep cultivation) reduces degradation and favorably affects many physical properties. Cultivation practices are probably essential on plains spoils and may be required on a continuing basis.

Furrows are very efficient as traps for snow and soil particles and may reduce erosion. However, furrows are usually persistent for a short time. Contour trenches may last longer than furrows but extensive damage may result if trenches fail. Furrowing is preferred to trenching in high elevation spoils.

There is no standard definition for "gouging" or "dozer basins". These treatments store more moisture than other surface manipulations. The nature of the underlying spoil strongly influences

the effect and longevity of the treatments. Swelling clays quickly eliminate positive effects. Gouging limits gully formation and erosion while runoff, and subsequently nutrient loss, is least in dozer basins. The life expectancy of dozer basins and gouging is probably less than five years, so that effective vegetation cover should be in place in that time. Topsoiling of these treatments increases the positive effects.

Gouging and dozer basin treatments may increase bulk density of some spoils. Moisture recharge of spoil is greater on chiselled and gouged sites than dozer basin sites, depending upon the spoil.

Use of plastics or soil conditioners to divert water to traps or depressions is effective but expensive. Efficiency and cost vary with materials used.

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16. CONSERVATION AND PLACEMENT OF SPOIL AND SOIL

Mine spoils are usually an inhospitable substrate for plant roots. Plants usually grow poorly or not at all on unimproved mine spoil. Typically then the original soil solum (the A and B horizons) is salvaged by removing and stockpiling it separately during mining and replacing it over the spoils later during reclamation. The time span over which salvaged soil materials is stored can influence its inherent fertility.

Gee and Bauer (1976) studied the effect of stockpile storage time on soil quality. The stockpiles were one to four years old. Storage did not reduce soil structural stability and the soil was significantly more stable than spoil. Soluble salt contents were low and pH was similar to that of adjacent undisturbed soils. The authors concluded that differences between the stockpiled soil solum and undisturbed soil solum may reflect mixing of subsoil C horizons with the solum during the stripping operation. In order to maintain a solum quality equivalent to that of adjacent undisturbed solum, mixing in the C horizon should be carefully avoided.

Work is presently under way on the effect of storage on the biological properties of stored topsoil spoil and peat in Alberta. Included in this is an assessment of mycorrhizal species and population dynamics. This research is being carried out by James Fujikawa of the Earth Sciences Division, Alberta Environment at Lethbridge and Professor Parkinson and his associates of the Biology Department, University of Calgary. Results are currently being prepared for publication. Little research has been reported of a rigorous nature on topsoiling spoil. Usually such experiments are extension oriented and combined with fertilization calibration trials.

Amendments are applied to mine wastes or tailings to enhance soil fertility and the establishment of vegetation. While the rationale for utilizing chemical fertilizers to enhance soil fertility is well known, that for incorporating amendments is less clearly perceived. Amendments including topsoil, fly or bottom ash, and peat have the potential to markedly increase yields for the following reasons:

(1) they may improve the nutrient status by directly supplying macro- and micronutrients and indirectly by masking or buffering toxicities such as heavy metals and salinity; (2) such amendments may increase the cation exchange capacity and moisture retention; and (3) less quantifiable, but significant, are potential improvements in structure, aeration, accumulation of organic matter, and increases in soil flora and fauna.

While topsoil is the most common surfacing material Dean, Havens and Valdez (1971) reported that rock and soil are frequently used. Smelter slag has also been used; however, soil replacement or capping has the advantage of permitting revegetation.

16.1 MULCHES

A mulch is any substance spread on the ground to protect plant roots from adverse temperature, to conserve moisture, or to enhance the rhizosphere in other ways. Mulches may also improve the soil by enhancing aeration, minimizing surface runoff, increasing infiltration, reducing wind and water erosion, and increasing snow catchment. They may also adversely affect revegetation by facilitating rodent, weed, disease, and insect population increases.

Using the previously presented definition of mulches, soil amendment itself can be considered a mulch. For example, on highly sodic spoil, Power, Ries and Sandoval (1976) reported that as little as 5 cm of solum over spoil prevented soil surface sealing by increasing infiltration and enhancing plant growth. They found that in North Dakota, 1 m of soil over spoil gave maximum productivity (Table 16.1), although productivity also depended on inherent soil fertility.

Peat can be used as a mulch. For example, Sheldon and Bradshaw (1977) experimented in vitro with peat on sand tailings in trays tilted at 35° to simulate tip slopes. While fertilization significantly depressed Lolium perenne and Trifolium repens establishment, sphagnum peat mulch eliminated this negative fertilization response (Figure 16.1).

Table 16.1. Spring wheat yield with up to 250 cm of C horizon plus solum soil, including 0, 20 or 190 cm of solum, North Dakota.

Total soil thickness (Subsoil and topsoil)	Topsoil thickness, (cm)			
	0	20	60	Mixed
cm			hL/ha	
10	10.4	ND	ND	13.7
31	13.8	20.8	ND	17.4
51	15.5	24.8	ND	19.1
71	16.7	25.3	25.4	19.5
91	16.4	25.2	26.1	20.2
112	16.2	25.7	26.6	19.2
132	17.1	25.3	26.6	19.6
152	16.2	26.3	25.1	18.8
173	16.4	24.9	26.0	18.8
193	16.3	26.2	26.9	19.9
213	ND	25.1	27.6	ND
234	ND	ND	25.8	ND
254	ND	ND	26.5	ND

Source: Adapted from Power, Ries and Sandoval (1976).
ND = No data.

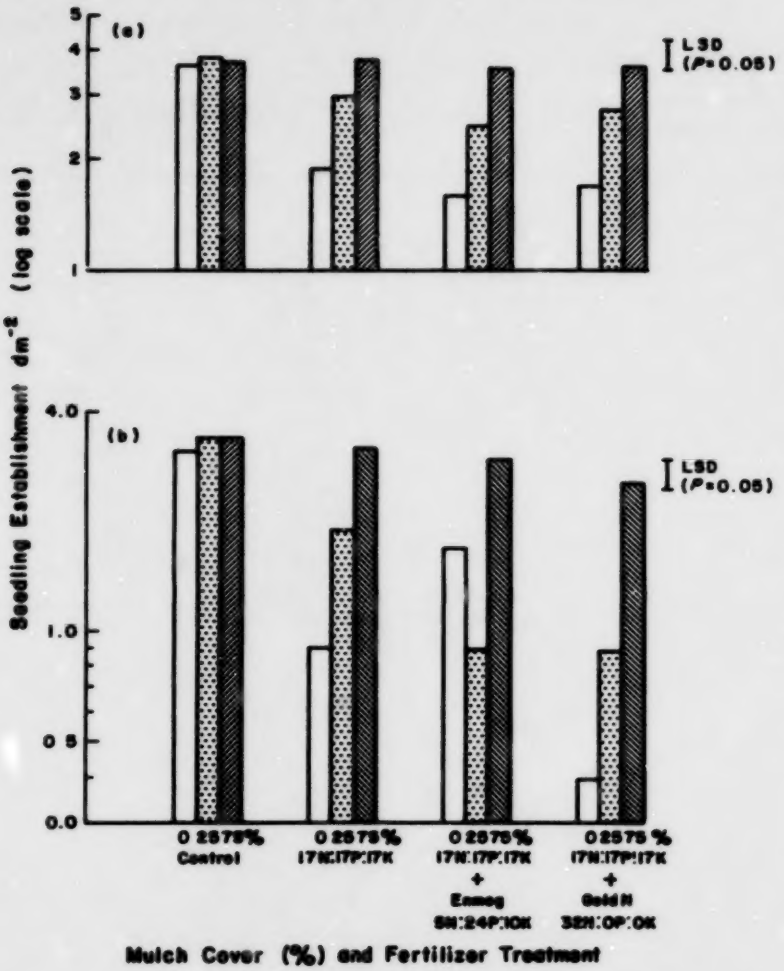

Figure 16.1. Effect of sphagnum peat mulches (%) on seedling establishment of (a) Lolium perenne and (b) Trifolium repens on China clay waste in the presence of four fertilizer treatments.

Source: Sheldon and Bradshaw (1977)

Zak (1977) studied 90 different mulch-grass treatment combinations on active sand dunes in Massachusetts with 12 grass species. Most of the mulches, except hay, jute, and asphalt deteriorate the seond year. Grasses were established by midsummer of the first year. Within 10 years, however, almost all of the seeded grasses were gone and Ammophila sp. was able to invade by taking advantage of the temporary stability provided by the introduced species. The author considered this to be a more economic method of stabilizing dunes than transplanting Ammophila directly.

Several authors studied the effect of mulches on soil temperature and moisture regimes. Day, Tucker and Thames (1979) measured soil moisture losses from coal spoil in Arizona after mulching or mixing with Hordeum vulgare straw or Salsola kali in proportions of 2:1 soil to mulch by volume. The in vitro study used two treatments: (1) 27°C, 0.54 relative humidity and (2) 21°C, 0.75 relative humidity. Both mulches significantly reduced soil moisture loss from the two soils and the coal spoil.

Graves and Carpenter (1978) tested the impacts of 0, 1.3, 2.5, 5, and 10 cm of saw mill residue mulch on soil moisture and temperature at various depths down to 120 cm. Soil temperature and soil moisture response to increasing mulch thickness were as follows:

Mulch Thickness cm	Soil Tempearature decline	Soil Moisture increase
0 to 1.3	yes	no
2.5 to 5	yes	yes
5 to 10	yes	yes

The authors noted that further increases in mulch thickness would probably increase soil moisture. Desirable rates of mulching depended on vegetation needs, the economics in comparison with alternative mulching systems, and the combined effect of the mulch and vegetation that became established.

Vogel (1975) used lime and a shredded bark mulch to amend acid coal spoils (pH 2.3 to 3.5) in Kentucky (Table 16.2). Mulching had a small ameliorating influence on the spoil by increasing infiltration and leaching of acids and salts (Table 16.3). Mulching also lowered spoil surface temperatures, thereby lowering evapotranspiration, capillary uptake, and surface salt crusting.

In Kentucky coal spoil, Carpenter, Graves and Kruspe (1978) used several types of mulches around trees to enhance moisture retention. They used 1 m x 1 m x 1.5 mm thick, clear polyethylene plastic, 1 m x 1 m fibreglass mats, 15 cm diameter discs, 30 cm diameter sprayed with latex rubber and bark chips spread in a 30 cm diameter circle. The spoil had a pH of 6.0 and a bulk density of 2.0 g/cm^3. The site was seeded to a mix of Festuca arundinacea cv. Kentucky 31 and Trifolium aureum for ground cover. Seedlings of Alnus glutinosa, Pinus taeda, and P. virginiana were planted at a spacing of 2 m x 2 m.

As Table 16.4 shows, the plastic fibreglass and latex spray treatments increased surface soil moisture content and temperature. The bark treatment acted as a wick enhancing evaporation and decreasing soil moisture content.

Kay (1976, 1977, 1978a,b, 1979) discussed organic mulches comprehensively, with regard to straw, hay, hydraulic mulching, wood residues and fibres or mats. Chemicals were discussed with regard to fibre tackifiers and soil binders as well as the effectiveness and economics of various soil and rock mulches. It was noted that mulch treatment choice is determined by site characteristics, availability of products, cost and effectiveness. In terms of cost, Kay found straw and hay offered the best protection with minimal weed and fire hazard problems. Hydraulic mulching may be weed free, low in fire hazard, and labour saving, but it is not always as effective as straw. Long fibres such as straw were shown to be a good investment compared with short fibres, chemicals, or mats.

Table 16.2. Chemical properties of acid spoils in Kentucky treated with 67 t/ha of lime (established in 1975).

Mulch treatment	Tillage	pH[a]	Total exchangeable acidity	Exchangeable aluminum	Specific conductance
No mulch	Shallow	6.1	0.4	0	0.82
	Deep	6.3	0.5	0	0.64
Mulch	Shallow	5.9	0.4	0	0.73
	Deep	5.8	0.4	0	0.53

Source: Adapted from Vogel (1975)
[a] pH is median value of three replications; other values are means of three replications.

Table 16.3. The effect of mulching and liming with agricultural and hydrated lime on total salt concentration in acid spoils in Kentucky.

	Total Salt Concentration meq/100 g soil					
Depth cm	No lime		Agricultural lime		Hydrated lime	
	No mulch	Mulch	No mulch	Mulch	No mulch	Mulch
1.5 to 8	18.0	14.0	0.1	0.0	0.0	0.0
10 to 17	15.0	20.0	20.5	4.5	16.0	0.1
19 to 25	22.0	23.5	19.0	6.9	18.0	3.0

Source: Adapted from Vogel (1975).

Table 16.4. Effect of individual tree mulches on the surface water content by volume and temperature of surface mine spoil in Kentucky on three dates in 1977.

Treatment	May 31 Moisture Content (percent)	May 31 Temperature (°F)	August 1 Moisture Content (percent)	August 1 Temperature (°F)	September 28 Moisture Content (percent)	September 28 Temperature (°F)
Clear plastic (1 x 1 m)	17	38	19	34	20	23
Fiberglass mat (1 x 1 m)	17	30	19	31	16	23
Latex spray	11	37	19	32	20	23
30 cm fiberglass disc	7	33	17	30	20	22
Control	14	36	19	33	20	20
15 cm fiberglass disc	6	35.5	19	30	20	20
Bark	0	36	5	32	20	22

Source: Carpenter, Graves, and Kruspe (1978b).

16.2 SOIL STABILIZERS

Dean, Havens and Valdez (1971) classified soil stabilizers into physical, chemical, and vegetative categories. Physical stabilizers include many materials such as coatings or protectors. Chemical stabilizers include resins, lignins, cements, waxes, cationic neoprene emulsions, organic polymers, bituminous products, etc., with costs and effectiveness varying widely. Specific products available as soil stabilizers include water dispersable viscous liquid alkalyd resins which form protective films over exposed soil, subsoil, or sand dunes (Eigenbrod 1971) and latex products which in effect glue seeds to the soil until germination, conserve soil moisture, and protect loose soils (Kranz 1974). Vegetative stabilization requires correction of adverse plant growth factors such as nutrient deficiencies, excess salinity, and heavy metal concentrations, and poor physical characteristics.

Plastic emulsions that bind soil particles together were termed "soil binders" by Kay (1978a) and are mixtures of high molecular weight polymeric particles dispersed in a continuous aqueous phase. They have been of limited use because of reported ineffectiveness and high cost. Although they are not toxic to plants, they may delay grass seed germination. Thus where soil binders are used, seeding rates are increased. Plastic emulsions are designed to break down biologically. Their useful life may be less than with many natural fibre mulches. In liquid concentrate form the amount of water added during application is critical, as poor performance is often due to excessive dilution. Uncured emulsions can be destroyed by frost heaving. Once broken, emulsion crusts will not self heal.

Chemical stabilizers and fertilizers are frequently included as part of hydroseeder slurry. The soil stabilizers, though, may significantly reduce grass and legume germination and establishment (see Chapter 34). These deleterious effects of the stabilizer, however, may be largely eliminated by applying sphagnum peat moss with the soil stabilizer (Sheldon and Bradshaw 1977).

Plass (1973, 1978) discussed the use of soil stabilizers including the combined use of stabilizers and mulches. Since

stabilizers are applied to the soil surface in water solutions, Plass suggests their effectiveness depends upon: (1) their dilution rate with water; (2) soil properties and climatic conditions which can influence the depth of infiltration; and (3) amendments addded to the solution to aid in vegetation establishment (Plass 1978).

Standard laboratory tests have been developed to measure weatherability of soil crusts formed from stabilizers and their effect on vegetation establishment. Especially important is the soil crust permeability to gases and water vapour. This allows gas exchange, conserves moisture by limiting evaporation without limiting infiltration, and allows germination (Plass 1978). Stabilizers also conserve seed and have the advantage of permitting seeding and stabilizer application in one operation.

In the humid eastern U.S., the crusts usually remain effective for six to eight weeks before they begin to degrade. Combining stabilizers and mulches may be cost effective compared to either treatment alone, while enhancing the specific benefits of each type of treatment on vegetation establishment.

Plass (1973) tested the effect of mulch-stabilizer mixes on erosion from acid coal spoil slopes (16 to 25°) with southern exposures (Table 16.5). The lowest erosion losses tended to occur on plots receiving mulch-stabilizer combinations, though not all such combinations produced low erosion losses. Those mulch-stabilizer combinations with low erosion losses also tended to have high growth rates, though colour (vigour) and density varied.

16.3 SOIL CONDITIONERS

In North America, the trend has been to use peat as an amendment only in its natural or bulk form. In Europe, derivatives of peat have also been used (e.g., Lopotko, Evadokimova and Puntus 1980; Tishkovich and Bulganina 1980). Perhaps the most widespread use of peat and coal derivatives as fertilizer and growth stimulant amendments has been developed in China in response to limited fertilizer sources (Wu,

Table 16.5. Effect of stabilizers and mulches on plant growth, vigour and erosion on a steeply sloping acid shale spoil in West Virginia.

Treatment	Rate per Acre	Average Height of Japanese Millet[a] (ft)	Foliage Color	Ground Cover Density	Sediment Loss per Acre (cu ft)
Control					
No mulch or soil stabilizer	-	1.6	G	L	309.5
Mulches					
Straw with Curasol AH	1½ tons with 40 gal	2.6	F	H	10.5
Hardwood bark	27 cu yd	2.1	P	M	52.3
Erocom	2 tons	1.4	G	M	183.0
Erocom	½ ton	1.7	F	M	172.6
Conwed No. 1	1,000 lb	1.6	F	H	52.3
Conwed No. 2	1,000 lb	1.5	P	H	94.2
PRM	500 lb	1.8	F	M	313.8
Soil Stabilizers					
Aquatain	10 lb	2.7	F	M	52.3
Terra-Tack	20 lb	1.6	F	L	204.0
Terra-Tack with wood fiber	20 lb with 400 lb	1.5	F	M	962.2
Curasol AH with wood fiber	40 gal with 800 lb	2.2	F	H	15.7
Aerospray 70 with wood fiber	80 gal with 800 lb	2.6	G	H	88.9
Aerospray 70 with wood fiber	40 gal with 400 lb	1.0	G	L	287.7
M-145	72 gal	1.8	G	M	83.7
M-145	18 gal	1.8	F	M	209.2
Genequa 743	55 gal	2.8	G	L	73.3
Genequa 163 with wood fiber	40 gal with 1,000 lb	1.9	F	L	109.8
XB - 2386	114 gal	2.7	G	L	172.6
XB - 2386 with wood fiber	75 gal with 600 lb	1.0	G	L	407.9

Source: Plass (1973).

[a] Measured at 10 randomly selected points on each plot.

[b] Subjective evaluation of the vegetation on the entire plot: G = no slight yellowing; P = pronounced yellowing.

[c] Estimated on each plot: H = 75 to 100 percent; M = 50 to 74 percent; L = 50 percent.

[d] Subplots with a slope of 20 degrees or more.

Guo and Yang 1979). Some very limited work on peat and coal derivatives for soil application has been done in Alberta.

Sulfomethylated humic acids extracted from peat and coal were studied for their potential as fertilizers and soil conditioners in reclamation of sandy soils (Moschopedis 1974). The assumption expressed intrinsically in Moschopedis' paper is that humic acids from peat and fine coal fragments will function similarly to natural humic acids studied in similar sandy soils. Low grade, weathered, sub-bituminous coal from the upper seam at Sheerness, Alberta was used for producing the sulfomethylated humic acids. In plot trials at Youngstown, Alberta yields of Bromus sp. and Lolium sp. were greater where the sulfomethylated humic acids were applied than where the equivalent amount of nitrates were applied, perhaps because of the added sulphur. Unlike traditional chemical fertilizers the sulfomethylated humic acids improved soil physical properties by increasing soil aggregation and moisture retention, and by reducing hydraulic conductivity and leaching (Table 16.6 to 16.9). These all represent significant soil improvements.

In an extention of the above research, Moschopedis and Mitchell (1974) applied sulfomethylated humic acids to spent Athabasca tar sands in growth chambers. The soil physical properties were improved (Tables 16.10 and 16.11) and significant initial growth response of Phalaris arundinacea occurred in response to both types of N after 30 days.

Aldon, Springfield, and Garcia (1975) mixed Pinus ponderosa bark with spoil or topsoil as a soil conditioner as 1:3 bark to soil; however yields of Secale cereale were reduced.

The reports dealing with chemical amendments for spoils or tailings indicated that the purpose of such amendments is usually to correct pH levels to aid plant growth. The most common way of raising soil pH levels is by liming. Liming techniques, effects on plant nutrients, acid drainage, and pedogenesis are also discussed in detail in other Chapters including 11, 12, and 46.

Table 16.6. Effect of sulfomethylated humates on mean weight diameter (MWD) of aggregates, Youngstown, Alberta.

Treatment	Application (%)	Sandy soil MWD (mm)
Control	0	0.21
Sulfomethylated humate	0.27	0.23
Sulfomethylated humate	0.54	0.57
Sulfomethylated humate	2.70	1.56
L.S.D. at 95% level of probability		0.02

Source: Moschopedis (1974).

Table 16.7. Effect of sulfomethylated humic acids on moisture-retention of sandy soils from Youngstown, Alberta.

Material	Humic acids in soils (%)	Moisture retention (%)
Control	0	5.9
Sulfomethylated humic acid	0.4	6.38
Sulfomethylated humic acid	0.8	8.89
Sulfomethylated humic acid	1.0	7.68
Sulfomethylated humic acid	2.0	10.27
Sulfomethylated humic acid	4.0	12.76
Sulfomethylated humic acid	8.0	19.17
Sulfomethylated humic acid	10.0	19.13

Source: Moschopedis (1974).

Table 16.8. Effect of various treatments on the hydraulic conductivity of sandy soil from Youngstown, Alberta.

Material	Nitrogen in solution (ppm)	Depth of water infiltration (cm/min) I	II	Average
Control	distilled water	0.26	0.26	0.26
Ammonium nitrate	300	0.18	0.18	0.18
Sulfomethylated humate	300	0.11	0.11	0.11
Ammonium sulfate	300	0.14	0.14	0.14
Ammonium nitrate	600	0.13	0.13	0.13
Sulfomethylated humate	600	0.03	0.03	0.03
Ammonium sulfate	600	0.11	0.12	0.12
L.S.D. at 95% level of probability				0.01

Source: Moschopedis (1974).

Table 16.9. Effect of various treatments on leaching rates of sandy soil from Youngstown, Alberta.

Material		Treatment		Leaching times for 35 cc solution[a]			Materials in leaching solutions (grams)
		Soil (g)	Amounts (g) of material to provide 100 and 200 ppm of N for each gram of soil	1st leaching (min.)	2nd leaching (min.)	Total leaching (min.)	
Control		50	ND	14	20	34	ND
Ammonium nitrate[b]	(35% N)	50	0.0142	18	22	40	0.015
Sulfomethylated humate	(3.7% N)	50	0.1350	27	23	50	0.090
Ammonium sulfate	(21% N)	50	0.0238	20	23	43	0.027
Ammonium nitrate	(35% N)	50	0.0284	15	21	36	0.025
Sulfomethylated humate	(3.7% N)	50	0.2700	35	35	70	0.095
Ammonium sulfate	(21% N)	50	0.0476	13	20	33	0.046

Source: Moschopedis (1974)

[a] L.S.D. at 95% level of probability = 0.78

[b] Reagent grade

Table 16.10. Effect of sulfomethylated humates on mean weight diameter (MWD) of aggregates of Suncor tailing sands, Alberta.

Treatment	Application (%)	G.C.O.S. Sand MWD (mm)
Control	0	0.292
Sulfomethylated Humate	0.27	0.325
Sulfomethylated Humate	0.54	0.343
Sulfomethylated Humate	2.70	0.397
L.S.C. at 95% level of probability		0.06

Source: Moschopedis and Mitchell (1974).

Table 16.11. Effect of sulfomethylated humates on the hydraulic conductivity of Suncor tailing sands, Alberta.

Material	Nitrogen In Solution (ppm)	Depth of Water Infiltration (cm/min)			Average
		I	II	III	
Control	Distilled Water	0.200	0.198	0.300	0.236
Sulfomethylated Humate	100	0.263	0.247	0.300	0.270
Sulfomethylated Humate	200	0.324	0.300	0.132	0.252
Sulfomethylated Humate	300	0.071	0.038	0.052	0.053
Sulfomethylated Humate	600	0.014	0.006	0.007	0.009
L.S.D. at 95% level of probability					0.116

Source: Moschopedis and Mitchell (1974).

Vogel (1975) studied the liming of acid Appalachian spoils, the effects on fertility, and the interactions with mulching. Appalachian mine spoils tend to be deficient in N and plant available P, but not in K. On these spoils, mulching tends to promote infiltration and leaching of excess salts. Combining liming with mulching therefore is usually preferable to liming alone to minimize acidic toxicities, including that from metals.

For assessing the lime requirement of acid Kentucky spoils of pH 2.3 to 3.5, Vogel (1975) used 1121 kg/ha of $CaCO_3$ per meq exchangeable acidity per 100 g spoil. As expected, liming increased pH, reduced exchangeable acidity, specific conductance, and exchangeable aluminum over time (Tables 16.12 to 16.15). It is also noteworthy that in the River Gem spoils of Kentucky, natural pedogenesis without amendment caused the spoil to undergo the same changes, with amendment accelerating some of these (e.g., pH increases; Table 16.12). Conversely, the Clay County spoils were more acidic and less dynamic. Consequently, the demonstrated effect of liming and mulching in the River Gem soils was more systematic even if more limited than the effects on the Clay County spoils. The Clay County spoil is clay textured as it is derived from shale and thus would be more highly buffered, whereas the River Gem spoils, being derived from sandstone, would be weakly buffered.

Chadwick (1973) applied several ameliorative treatments to acidic spoil in northern England, including limestone, wood waste, sewage sludge, cationic bitumen emulsion "Arganifax", broiler manure, pulverized fuel ash, and commercial fertilizers. While the organic additives and fuel ash had no effect, limestone was the most effective in raising the pH. Cationic bitumen emulsion also raised soil pH.

Zimmerman and Moore (1976, 1977) discussed reclamation and revegetation of asbestos tailings in Quebec. They reported some evidence that the Ca:Mg ratio must be corrected in favour of Ca for legumes. Although Ca was applied as tri-calcium phosphate, an additional Ca dose in a more available form was desirable. Gypsum was considered the preferred Ca form for this purpose. Retention and

Table 16.12. Spoil pH 1972 to 1975 on plots established in 1972 in Kentucky.

Treatment	Year				
	72[a]	72	73	74	75
Clay County spoils					
1. None	2.4[b]	2.2	2.4	2.5	2.7
2. Fertilizer	2.4	2.2	2.4	2.5	2.6
3. Fertilizer + mulch	2.4	2.3	2.5	2.6	2.7
4. Lime	2.3	2.7	3.2	4.1	3.1
5. Lime + fertilizer	2.4	2.4	4.8	3.1	3.1
6. Lime + fertilizer + mulch	2.3	2.8	4.5	5.7	4.5
River Gem spoils					
1. None	3.2[c]	3.1	3.3	3.3	3.6
2. Fertilizer	2.5	3.1	2.9	3.3	3.4
3. Fertilizer + mulch	3.1	3.1	3.7	3.5	3.6
4. Lime	3.1	4.1	4.2	4.1	3.4
5. Lime + fertilizer	3.0	4.1	4.7	4.6	4.0
6. Lime + fertilizer	3.0	4.6	4.4	5.8	4.8

Source: Vogel (1975).
[a] Values before application of treatments.
[b] Median pH of 2 replications.
[c] Median pH of 3 replications.

Table 16.13. Specific conductance of spoils 1972 to 1975 on plots established in 1972 in Kentucky in mmhos/cm.

Treatment	Year				
	72[a]	72	73	74	75
Clay County spoils					
1. None	4.10[b]	4.11	3.45	2.55	1.28
2. Fertilizer	4.00	4.13	3.82	2.40	1.44
3. Fertilizer + mulch	3.75	3.56	1.63	1.39	1.00
4. Lime	4.10	3.52	2.84	1.38	2.15
5. Lime + fertilizer	4.15	4.02	2.58	2.05	1.93
6. Lime + fertilizer + mulch	4.00	3.21	2.50	1.20	1.20
River Gem spoils					
1. None	1.80[c]	2.74	1.04	.82	.74
2. Fertilizer	2.95	3.13	1.12	1.08	.63
3. Fertilizer + mulch	1.72	1.76	.84	.46	.29
4. Lime	1.76	2.90	1.12	.95	1.02
5. Lime + fertilizer	2.32	3.25	1.09	.80	.67
6. Lime + fertilizer + mulch	1.90	2.00	.33	.43	.26

Source: Vogel (1975).
[a] Values before application of treatments.
[b] Mean of 2 replication.
[c] Mean of 3 replication.

Table 16.14. Total exchangeable acidity[a] of spoils 1972 to 1975 on plots established in 1972, in Kentucky in meq/100 g.

Treatment	Year				
	72[b]	72	73	74	75
Clay County spoils					
1. None	13.50[c]	24.24	13.50	10.45	9.30
2. Fertilizer	13.25	26.75	13.50	10.30	9.20
3. Fertilizer + mulch	12.25	21.25	8.00	7.71	7.20
4. Lime	14.25	9.25	2.23	2.98	7.95
5. Lime + fertilizer	15.50	13.00	.08	5.65	5.25
6. Lime + fertilizer + mulch	13.25	8.00	.10	.53	2.20
River Gem spoils					
1. None	6.92[d]	10.05	6.60	6.20	8.07
2. Fertilizer	9.77	12.15	8.32	7.53	8.73
3. Fertilizer + mulch	6.48	6.10	6.08	6.52	7.43
4. Lime	9.35	2.43	3.73	2.40	10.10
5. Lime + fertilizer	9.95	1.85	0.32	0.92	4.57
6. Lime + fertilizer + mulch	7.28	2.03	1.85	0.20	2.83

Source: Vogel (1975).

[a] the official canadian term is exchange acidity (Glossary of Terms in Soil Science, 1976 Agriculture Canada Publication 1459 pp 18).

[b] Values before application of treatments.

[c] Mean of 2 replications.

[d] Mean of 3 replications.

Table 16.15. Exchangeable aluminum of spoils 1972 to 1975 on plots established in 1972 in Kentucky in meq/100 g.

Treatment	Year				
	72[a]	72	73	74	75
Clay County spoils					
1. None	6.00[b]	13.50	6.00	5.50	5.00
2. Fertilizer	5.50	13.00	6.00	5.35	4.35
3. Fertilizer + mulch	5.00	9.25	3.75	3.58	3.50
4. Lime	5.50	6.75	1.78	1.63	4.30
5. Lime + fertilizer	5.75	10.25	0.00	3.83	2.90
6. Lime + fertilizer + mulch	5.75	6.50	0.00	0.25	1.45
River Gem spoils					
1. None	5.68[a]	3.23	5.25	4.92	6.93
2. Fertilizer	7.18	9.88	6.47	6.15	7.17
3. Fertilizer + mulch	5.28	4.73	4.25	5.10	6.33
4. Lime	6.67	1.97	2.97	1.95	6.00
5. Lime + fertilizer	7.47	1.57	0.15	0.67	4.20
6. Lime + fertilizer + mulch	5.87	1.77	1.57	0.00	2.77

Source: Vogel (1975).
[a] Values before application of treatments
[b] Mean of 2 replications.
[c] Mean of 3 replications.

availability of N was also discussed (Zimmerman and Moore 1977). The limiting factors include the low anion retention capacity of coarse textured alkaline tailings, volatilization of NH_4-N, rapid leaching of NO_3 and NH_4, and slow bio-oxidation of slow release N fertilizers such as sulfur coated urea. They suggest using spent sulfite liquor to increase the acid forms of organic matter, to increase anion retention, and to enlarge the organic component supporting the various biochemical reactions of the soil phase of the nitrogen cycle. Attempts to test this theory have not been successful, although it is not clear whether the poor response was due to adverse climatic conditions or the impact of acidity on tailings properties such as increased solubility of heavy metals.

16.4 SOIL RECONSTRUCTION

This section deals with amendments that are available to the reclamationist on site, such as topsoil, peat, and overburden. Amendments used in soil reconstruction which are not immediately available such as sewage, ash, gypsum, and fertilizer are dealt with in other sections of this report.

A popular method of determining the optimum depth of topsoil over mine spoil utilizes a soil wedge whereby the applied topsoil depth is increased from zero to beyond the expected optimum depth for plant growth.

McAllister Environmental Services Ltd. (1978) used the soil wedge concept to study topsoiling with Modeste sandy loam and Wabamun clay over mine spoil in the Highvale area near Edmonton. Also included in the experimental design were fly ash, gypsum, and peat amendments. The soil wedges were 37 m x 44 m with 0 to 1 m of topsoil. Peat was applied 15 cm deep on a 9 m strip across the plot. Gypsum was applied at 22 t/ha on a 37 m swath down the centre of the plot. Fly ash was applied on a 6 m swath down the centre of the plot. There was a 3 m overlap of gypsum and fly ash. The physical and chemical properties of the spoil and soils are described in Tables 16.16 and 16.17.

Table 16.16. Certain physical and chemical characteristics of the growth media surfacing and underlying mine spoil at selected depths on the Highvale Mine wedge plots, Alberta, May 1977.

Growth Media[a]	Physical and Chemical Characteristics				
	Sample Depth (m)	Saturation %	EC mmhos/cm	SAR	Sodium meq/L[b]
Modeste Sandy Loam	0 to 0.3	49	2.0	1.2	3.7
" " "	0.3 to 0.6	49	0.9	1.8	2.5
" " "	0.6 to 0.9	49	1.8	6.8	11.1
Underlying Mine Spoil	0.9 to 1.2	72	3.7	18.6	29.6
Modeste Sandy Loam	0 to 0.3	49	2.8	9.6	2.6
" " "	0.3 to 0.6	50	2.6	9.2	7.4
Underlying Mine Spoil	0.6 to 0.9	56	4.4	7.0	24.4
Modeste Sandy Loam	0 to 0.3	46	3.0	1.5	5.7
Underlying Mine Spoil	0.3 to 0.6	50	2.1	5.4	11.3
Wabamun Clay Loam	0 to 0.3	72	1.2	2.6	4.3
" " "	0.3 to 0.6	71	0.9	2.6	3.5
" " "	0.6 to 0.9	66	0.8	2.7	3.0
Underlying Mine Spoil	0.9 to 1.2	75	2.1	9.0	13.3
Wabamun Clay Loam	0 to 0.3	65	3.0	1.3	5.1
" " "	0.3 to 0.6	67	2.5	3.7	10.5
Underlying Mine Spoil	0.6 to 0.9	81	3.3	13.1	24.8
Wabamun Clay Loam	0 to 0.3	66	3.4	2.7	10.4
Underlying Mine Spoil	N.A.	N.A.	N.A.	N.A.	N.A.
Mine Spoil (No surfacing)	0 to 0.3	63	3.1	21.7	35.3

Source: McAllister Environmental Services Ltd. (1978).
Used by permission of TransAlta Utilities Corporation.

[a] Placed as wedges 120' x 145' and tapering from 3' to 0' in thickness over Mine Spoil. Samples for analysis were taken where melia 3', 2' and 1' thick.

[b] Water soluble ion.

Table 16.17. Salinity analysis of overburden strata taken at two points on highwall of Highvale Mine, Alberta, August 1976.

Location	Description	EC mmhos/cm	SAR
West Pit [a]	Wabamun Clay	0.3	1.0
" "	Weathered Sandstone	0.3	1.5
" "	Dark Sandy Clay Loam	0.5	16.6
" "	Sandy Loam	0.7	25.5
" "	Dark Gray Shale (soft)	1.0	34.2
" "	" " " (stratified)	1.1	41.3
East Pit [b]	Sandstone (light gray)	0.9	32.7
" "	Dark Gray Shale	1.5	22.7
" "	Dark Sandstone	0.8	33.8
" "	Shale	0.8	33.8
" "	Shale	0.9	34.5

Source: McAllister Environmental Services Ltd. (1978b).
Used by permission of TransAlta Utilities Corporation.

[a] The materials listed below Wabamun Clay make up about 70 to 80% of mine spoil at this site.

[b] These materials comprise over 80% of mine spoil at this site.

The 30 cm Modeste loam treatment produced higher barley yields than the 1 m treatment (Table 16.18) due to a greater moisture deficit in the latter treatment. McAllister Environmental Services Ltd. contended that the tendency to moisture deficiency was greater in the topsoil than in the spoil. In the shallow topsoil treatment (30 cm topsoil) he suggested plants were able to extract moisture from the underlying spoil, whereas in the deeper topsoil treatment (1 m topsoil), less moisture was extracted from the underlying spoil and a significant moisture deficiency developed in the topsoil. In the Wabamun clay, soil thickness had no consistent effect. Gypsum increased yield especially with the coarser textured Modeste soil (Table 16.18). Fly ash amendment increased soil selenium levels but not to toxic levels.

Soil samples taken at the end of the second growing season (McAllister Environmental Services Ltd. 1979) indicated that both surfacing materials had become slightly more sodic and saline at the spoil/soil interface (Table 16.19). The SAR was higher in the clay material. Due to the sampling design it was not possible to determine the effects of the gypsum treatment. The authors cautioned against any long-term extrapolations of these results. They noted, however, that there was little indication of future deleterious effects.

McAllister Environmental Services Ltd. (1977 a,b) also tested the effects of an Ah layer placed over various coal overburden materials. Further details are presented in Chapter 33; however, topsoiling generally improved establishment and yield of barley. The authors noted that future cultivation of plots with a shallow topsoil layer would cause mixing of overburden with topsoil. This mixing would be expected to reduce yields.

In a third trial, McAllister Environmental Services Ltd. (1977a) tested the effects of five potential growth media with or without topsoil on yield of Hordeum vulgare. Trenches 61 m long, 4.3 m wide and 1.2 to 1.5 m deep were excavated. The Ah horizon and glacial till, including C horizon (0.9 to 1.5 m depth), were selectively removed

Table 16.18. The yield of barley grown on mine spoil as influenced by spoil surfacing with selected growth media Highvale Mine, Wedge Plots, Alberta 1976.

Surface Treatment			Barley Bushels/Acre[a]		
Growth Media	Thickness (m)	Soil Amendment	Yield Per Plot	Average Media Yield	Increase Due to Surfacing
Unsurfaced Spoil	--	Nil	6.3		
Unsurfaced Spoil	--	Gypsum	14.8	10.6	--
Wabamun Clay [bd]	00.3	Nil	22.1		
Wabamun Clay	00.3	Gypsum	25.2	23.7	13.1
Wabamun Clay	0.9	Nil	22.9		
Wabamun Clay	0.9	Gypsum	23.3	23.1	12.5
Modeste Sandy Loam [cd]	00.3	Nil	15.4		
Modeste Sandy Loam	00.3	Gypsum	24.8	20.1	9.5
Modeste Sandy Loam	0.9	Nil	11.9		
Modeste Sandy Loam	0.9	Gypsum	19.1	15.5	4.9
Peat [e]	0.15	Nil	21.1	21.1	10.5

Source: McAllister Environmental Services Ltd. (1978b).
Used by permission of TransAlta Utilities Corporation.

[a] Least significant difference 4.6 bushels at 5% level.

[b] A local soil of lacustrine origin. Alberta Soil Survey Report No. 87.

[c] A local soil developed on residual material (Paskapoo Formation). Alberta Soil Survey Report No. 87.

[d] Built as a wedge 36.6 X 44.2 m and tapered from 20.9 to 0 m in thickness. Yield measurements were taken at thickness indicated.

[e] Applied 0.15 m in thickness.

Table 16.19. Comparison of electrical conductivity (EC) and SAR values of growth media at selected depths on the Highvale Mine wedge plots as of 12 May 1977 and 18 October 1978.

Growth Media	Depth Sampled (cm)	EC(mmhos/cm) May 1977	EC(mmhos/cm) Oct. 1978	EC(mmhos/cm) Change[a]	SAR May 1977	SAR Oct. 1978	SAR Change[a]
Modeste Sandy Loam[b]	0- 30	2.0	1.8	(0.2)	1.2	0.9	(0.3)
Modeste Sandy Loam	30- 60	0.9	1.0	0.1	1.8	0.8	(1.0)
Modeste Sandy Loam	60- 91	1.8	0.7	(1.1)	6.8	1.4	(5.4)
Underlying Mine Spoil	91-122	3.7	2.4	(1.3)	18.6	18.5	(0.1)
Modeste Sandy Loam	0- 30	2.8	1.2	(1.6)	0.6	0.8	0.2
Modeste Sandy Loam	30- 60	2.6	1.2	(1.4)	2.2	3.9	1.7
Underlying Mine Spoil	60- 91	4.4	2.5	(1.9)	7.0	15.5	8.5
Modeste Sandy Loam	0- 30	3.0	2.4	(0.6)	1.5	1.2	(0.3)
Underlying Mine Spoil	30- 60	2.1	2.2	0.1	5.4	15.4	10.0
Wabamun Clay Loam[b]	0- 30	1.2	1.5	0.3	2.6	1.5	(0.9)
Wabamun Clay Loam	30- 60	0.9	0.5	(0.4)	2.6	1.7	(0.9)
Wabamun Clay Loam	60- 91	0.8	0.6	(0.2)	2.7	3.5	0.8
Underlying Mine Spoil	91-122	2.1	2.7	0.6	9.0	10.4	1.4
Wabamun Clay Loam	0- 30	3.0	2.8	(0.2)	1.3	2.5	1.2
Wabamun Clay Loam	30- 60	2.5	2.7	0.3	3.7	8.6	4.9
Underlying Mine Spoil	60- 91	3.3	3.4	0.1	13.1	22.5	9.4
Wabamun Clay Loam	0- 30	3.4	2.5	(0.9)	2.7	7.7	5.0
Underlying Mine Spoil	30- 60	n.a.	4.5	-	n.a.	19.1	-
Mine Spoil (not surfaced)	0- 30	3.1	4.0	0.9	21.7	16.9	(4.8)

Source: McAllister Environmental Services Ltd. (1979b).
Used by permission of TransAlta Utilities Corporation.

[a] Change since 1977.

[b] Placed as wedges 36 m wide x 44 m long with media tapering from 0.0 cm to 91 cm in thickness over levelled mine spoil. Samples were taken on traverses where wedges are 30, 60 and 91 cm in thickness.

from four trenches, and stockpiled. The fifth trench was excavated to a depth of 1.2 m with no selective handling of material.

The trenches were brought up to a uniform depth of 1.2 m with surplus subsoil then filled as follows:

1. mixture 75% till and 25% shale from recent mining;
2. mixed mine run spoil from an old spoil pile;
3. till;
4. upper 1.2 m of original spoil (mixed); and
5. mixture 50% till and 50% shale.

The authors noted that a 1.2 m depth was chosen as the roots of cereal crops normally penetrate 0.9 to 1.2 m into soil under good growth conditions. One half of each plot was surfaced with 15 cm of topsoil. Details of the crop yield data are reported in Chapter 33. In general, yields were higher on topsoiled plots. When shale content increased to 50%, yields were depressed.

Soil samples from the upper 15 cm of the trenches taken three months after filling showed that SAR in Trenches 2 and 5 was higher (11.8 and 12.0, respectively) than the other trenches indicating an expected yield depression. Electrical conductivity was also greater in these plots. The shale used in the study had an SAR of 15.2 to 17.9 and conductivity of 1.7 to 2.7 mmhos/cm. The mine run spoil SAR was 18.4 and conductivity was 3.1 mmhos/cm.

The till in Trench 3 was a mixture of tills from the lower 0.6 m of Trenches 1, 2, 3, and 5. Analyses of the mixed till (Table 16.20) showed that it had characteristics intermediate between the "good to very good" Angus Loam (Trench 1) and "fair to fairly good" Gleysolic soil found in Trench 5. The authors noted this suggested that: (1) the supply of favourable growth media may be increased by the blending of certain favourable and unfavourable media; (2) appropriate blending may offer cost savings in reclamation; and (3) the uniformity of the post-reclamation soil may be enhanced by mixing growth media.

Further soils tests revealed that N and P were required to enhance soil fertility. No consistent pattern of soil nutrient deficiency was evident among growth media.

Table 16.20. Analytical data for unblended and blended tills, Round Hill, Alberta.

	UNBLENDED		BLENDED
	Angus Ridge[a]	Gleysolic[b]	Trench 3
Saturation %	49	76 to 104	43
pH	7.7	8.0 to 8.1	7.5
Conductivity	3.5	9.2 to 10.7	4.0
SAR	2.6	14.5 to 18.4	5.8

Source: Adapted from McAllister Environmental Services Ltd. (1977a). Used by permission of TransAlta Utilities Corporation.

[a] An eluviated black soil with an agricultural productin ability rating of "good to very good." Sample from a depth of 1.4 to 1.9 m.

[b] A gleysolic soil (impaired by excessive surface water) rated as "fair to fairly good". Values are a range from three sample depths (0.9 to 1.2 m, 1.2 m to 1.5 m, greater than 1.5 m).

Table 16.21. Soil and spoil characteristics at the Navajo Mine in New Mexico.

	Plot 1 Spoil	Plot 2 Spoil	Topsoil
Sieve Analysis			
> 5.6 mm	25.3	20.7	5.5
1.7 to 5.6 mm	24.1	17.2	3.2
< 1.7 mm	50.6	62.1	91.3
Hydrometer Analysis			
% sand	33.4	54.5	83.7
% silt	30.8	19.4	7.7
% clay	35.8	26.1	8.6
Colour	dark gray brown	red brown	light
pH	6.8	6.3	8.2
Water holding capacity (%)	55	46	31
Salinity (ppm)	1400	950	140

Source: Wahlquist, Dressler and Sowards (1975).

Power, Ries and Sandoval (1976) found that a 5 cm layer of topsoil over an impermeable, highly sodic coal spoil at the Glenharold Mine, Stanton, North Dakota improved plant production and reduced surface crusting and runoff. Infiltration rate in a one-hour test increased from 7.3 cm/hr on raw spoils to 16.4 cm/hr on spoils with the topsoil. They noted that much of the effect of the topsoil was lost if it was incorporated into the spoil.

Wahlquist, Dressler and Sowards (1975) briefly reported on the results of topsoiling with sandy saline topsoil over clay loam and sandy clay loam textured spoil (Table 16.21) in arid north-western New Mexico. Although little soils data are presented, topsoiling did, in this case, increase infiltration (Figure 16.2).

Dollhopf and Majerus (1975) initiated a series of topsoiling related studies in the Colstrip, Montana area. In one study, they used a clay buffer to retard capillary uptake of salts from spoil and topsoil. No results were reported, although the design of the experiments suggests they should be relevant to Alberta conditions.

In a separate study, Dollhopf used various thicknesses of subsoil as a buffer between topsoil and spoil. The subsoil had considerably more salts and Na than either the red clay or topsoil and, as he later mentioned, than the spoil itself and is unsuited as a buffer, jeopardizing the value of the experiment. The most significant result of the experiment was that precipitation facilitated downward leaching of salts, especially in the 0 to 10 cm soil depth where salt levels decreased in response to the precipitation events.

Sindelar, Hodder and Majerus (1973), at the Rosebud Mine in the Colstrip area of Montana, studied the effects of topsoiling and mulches on soil properties, plant rooting characteristics, and plant biomass production. In one study, applying saline topsoil over more saline spoil (Table 16.22) increased plant production at up to 10 cm topsoil but not at 20 cm of topsoil depth (Table 16.23).

In a separate study, 15 to 20 cm of topsoil, 15 to 20 cm of subsoil, and raw spoil along with Hordeum straw and fibre straw mulch treatments were used to compare the germination and establishment

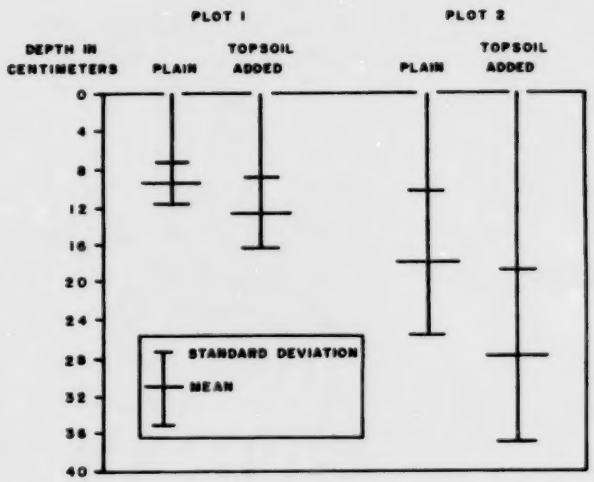

Figure 16.2. Effect of topsoil on infiltration rate in two coal spoil types at the Navajo Mine, New Mexico. Plot 1: High shale. Plot 2: Moderate texture overburden.

Source: Wahlquist, Dressler and Sowards (1975)

Table 16.22. Soil analyses from topsoil depth plots at Colstrip, Montana (May 1972).

	pH	P	K	Salts Conductivity	Organic Matter	Ca	Mg	Na
Topsoil[a]	8.2	29	190	0.3	0.60	12	2.10	0.45
Raw spoils[b]	8.4	18	64	0.5	0.15	16	2.26	0.46

Source: Sindelar, Hodder and Majerus (1973).
[a] Average of nine plots.
[b] Average of three plots.

Table 16.23. Total above ground plant production of four topsoil depth treatments at Colstrip, Montana.

Treatment	Depth (cm)	Production[a] (g/m^2)
1	0	16.2 a
2	5	27.2 b
3	10	34.4 c
4	20	32.9 c

Source: Adapted from Sindelar, Hodder and Majerus (1973).
[a] Means followed by the same letter are ot significantly different at the 95% level of significance.

potential of topsoiled spoil against surface mulched and non-mulched subsoil over spoil (Sindelar, Hodder and Majerus 1973). Plant production only was reported and suggested mulching and topsoiling had no beneficial effect on subsoiled spoil (Table 16.24). Topsoil did, however, increase weed growth at the expense of Triticum aestivum growth.

Some work was done by Sindelar et al. (1974) at Colstrip, Montana, on the effect of topsoiling on rooting depth and the contribution of plant biomass to organic matter accumulation. Initial estimates suggested root production can contribute in excess of 16 000 kg/ha of organic matter in the 0 to 45 cm soil depth layer. In the same study, root production had reached about 45% of that on native grazed soils three years after reclamation. Also, after 40 years of natural revegetation of raw coal spoil, root biomass reached 11 000 kg/ha. This suggests that for this spoil, natural pedogenesis in the spoil will restore its plant productivity over long periods of time. Topsoiling this spoil to increase plant productivity over a short time span achieved moderate success, but was not able to restore productivity to premining levels.

Michelutti (1974) studied the effect of topsoiling over iron sulfide tailings in northern Ontario with different thicknesses of four locally available soils. Thicknesses of 2.5, 5, 10, and 15 cm of sand to loam textured soils were placed, without incorporation, over the tailings. The soils were fertilized with 22 t/ha limestone and 1.3 t/ha fertilizer. After two months growth the best legume yields were on black loam textured soil, 15 cm thick (Figure 16.3). Legume yields and vigour exceeded that of the grasses tested.

Peat may be used as a surface amendment alone, or in conjunction with topsoil. Peat has an advantage over other organic amendments such as sewage sludge and manure as it is low in nutrients and can thus be used to improve soil structure without risking toxicities. The high cation exchange capacity of peat acts as a buffer absorbing excess cations, and reducing nutrient, chemical, and metal toxicities (Sheldon and Bradshaw 1977).

Table 16.24. Wheat, weed, and total production on soils media plots at Rosebud Mine Colstrip area of Montana (July 20, 1972, gms/m^2).

	Topsoil	Subsoil	Raw Spoils
Wheat			
Control	232.9	326.9	285.8
Straw mulch	203.8	269.9	397.0
Silva-fiber	211.0	293.4	297.9
$\bar{x}$	215.9 a	296.7 b	326.9 b
Weeds			
Control	240.9	166.6	121.4
Straw mulch	232.2	179.4	151.6
Silva-fiber	266.9	91.6	88.0
$\bar{x}$	246.7 a	145.9 b	120.3 b
Total Production			
Control	473.0	493.5	407.1
Straw mulch	436.0	449.3	548.6
Silva-fiber	477.9	385.0	385.9
$\bar{x}$	462.3 a	422.6 a	447.2 a

Source: Adapted from Sindelar, Hodder and Majerus (1973).
Note: Means followed by same letter not different at 95% level of significance.

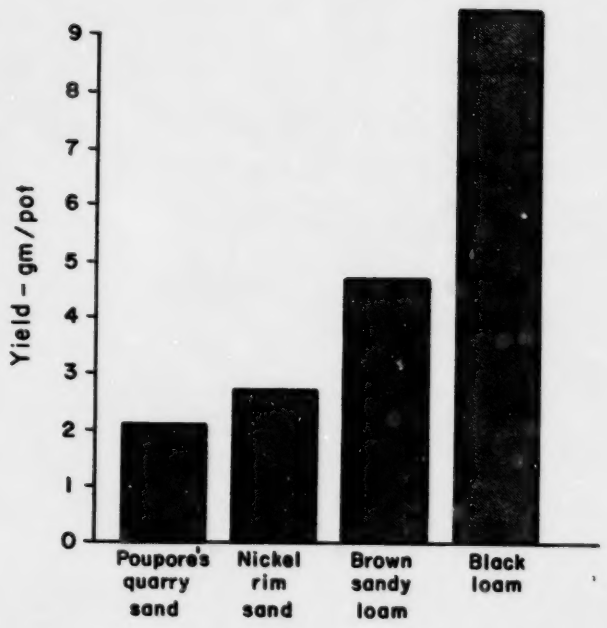

Figure 16.3. Effect on legume yield of various topsoil materials placed over iron sulphide tailings from the Sudbury area.

Source: Michelutti (1974)

Research on peat as an aid to reclamation in Alberta has centered mainly in the north-east oil sands region. Rowell (1977 a,b, 1978, 1979), Takyi et al. (1977), Berry and Klym (1974), and Berry (1970) have studied the effects on plant establishment of adding peat or peat plus overburden to spent tailings. Details of the methodology and results may be found in greater detail in Chapter 33. In general, the addition of peat increased growth and yield of grasses and legumes. Mixing the peat into the tailings produced better growth than leaving the material as a layer on the surface.

As noted above, the primary objective of much of this work has been to evaluate vegetation and species response to various amendments rather than specific soils studies. The soil reconstruction work which has been undertaken has tended to focus on soil nutrient dynamics or cycling, and organic matter decomposition with minor references to soil moisture regimes.

In growth chamber studies, Takyi et al. (1977) experimented with various mixes of tailings sand, Syncrude overburden, Suncor (GCOS) overburden, agricultural soil, peat, heavy oil sand, and lean oil sand (Table 16.25). The lean and heavy oil sand induced some toxicity effects which, it was suggested, were primarily due to its bitumen content. Mixing such materials with productive agricultural mineral soil greatly ameliorated these effects. The bitumen did degrade in situ and this was accelerated by soil amendment (Table 16.26). In one growth chamber pot experiment using tailings sand, peat, and overburden from Suncor in a 2:1:1 ratio by volume, the vegetation responses to salinization were studied. Such studies are relevant since certain portions of the overburden can be highly saline. The soil pH response in this experiment is illustrated in Table 16.27.

Using a similar tailings sand, peat, and overburden pot mix and growth chamber approach Takyi et al. (1977) studied the soil and vegetation response to pH manipulation with H_2SO_4 and Na_2CO_3. After nine months and two harvests, significant pH adjustment and buffering had occurred (e.g., Table 16.28). The buffering capacity of the various materials tested for reconstruction was also studied (Figures 16.4 to

Table 16.25. Properties of soils and other related materials from Syncrude and G.C.O.S. leases at Fort McMurray, used in growth chamber studies.

Materials	pH	Cond. mmho per cm	NH_4^+ ppm	NO_3^- ppm	Total mineral N ppm	Org. C %	Organic matter %	P ppm	K ppm	Na ppm	Ca ppm	$CaCO_3$ equiv. %	Total N %	Sulfate S ppm
Tailings sand	7.89	0.55	1.06	0.53	1.59	0.20	ND	3.5	12.5	75	75	ND	0.005	11.4
Syncrude overburden	7.40	2.46	0.18	trace	0.18	1.24	ND	3.5	32.5	65	1870	4.48	0.019	278.4
GCOS overburden	7.75	1.51	trace	trace	trace	1.89	ND	3.5	60.0	75	1555	3.53	0.024	232.0
Agricultural soil (Malmo)	6.05	0.52	3.37	15.96	19.33	6.37	10.96	11.5	150.0	85	4950	ND	0.450	9.5
Heavy oil sand (GCOS mine site)	5.70	0.19	trace	trace	trace	10.70	ND	2.5	12.5	80	90	ND	0.049	48.0
Lean oil sand (air-dried)	6.75	0.15	trace	trace	trace	6.12	ND	2.0	7.5	45	145	ND	0.037	6.3
Peat (GCOS, drained)	4.10	0.16	trace	trace	trace	56.75	97.60	4.0	130.0	230	3250	ND	0.863	460.0

Materials	Exchange complex, me/100 g					Particle size distribution, %			moisture at field capacity (1/3 bar)	oil mg/g (o.b. soil)
	CEC	K	Ca	Na	Mg	Sand	Silt	Clay		
Tailings sand	2.9	0.26	0.25	0.43	0.48	96.6	1.0	2.4	14	1.4
Syncrude overburden	3.9	0.64	12.00	0.43	1.70	64.8	18.4	16.8	18	9.6
GCOS overburden	3.9	1.30	13.25	0.43	2.80	59.9	21.0	19.1	18	10.5
Agricultural soil (Malmo)	37.8	3.80	31.75	0.43	4.80	38.4	45.2	16.4	30	ND
Heavy oil sand (GCOS mine site)	2.9	0.64	0.25	0.43	0.48	68.0	30.4	1.6	14*	141.4
Lean oil sand (air-dried)	2.9	0.26	5.00	0.22	0.35	96.2	0.6	3.2	14	79.3
Peat (GCOS, drained)	127.1	3.80	33.25	0.65	9.04	ND	ND	ND	250**	ND

Source: Takyi et al. (1977)

* 5% field moist
**on an air dry basis

Table 16.26. Oil content of lean and heavy oil sands from Fort McMurray, Alberta before and after two seedings (30 December 1974 to 28 September 1975).

	Original Bitumen Content (%)	Amount of Original Oil Decomposed (%)
Pre-seeding (Dec. 30, 1974)		
Fresh heavy oil sand	14.14	--
Lean oil sand	7.83	--
Malmo-fresh heavy oil sand mix	6.53	--
After two seedings (Sept. 28, 1975)		
Lean oil sand	7.22	7.79
Malmo-fresh heavy oil sand mix	4.80	26.49
Decomposing heavy oil sand[a]	10.67	24.54
Equivalent of original heavy oil sand remaining[b]	10.40	26.45

Source: Takyi et al. 1977.

[a] Lumps still recognizable as heavy oil sand in the mix with Malmo.

[b] Based on 4.80% oil left in the Malmo-heavy oil sand mix in relation to the pre-seeding bitumen content of the fresh heavy oil sand.

Table 16.27 Mean pH and salinity levels of soil mix at harvest of the second seeding on Alberta Oil Sands overburden.

		Check (S_o)	Low (S_1)	Medium (S_2)	High (S_3)
pH		7.29	7.19	7.31	7.37
Conductivity (mmho/cm)		1.40	7.91	12.16	17.97
Conductivity (mmho/cm)[a]					
	0-1"	nd	6.57	14.37	20.71
	1-2"	nd	5.82	10.13	15.58
(rest of pot)	2-4"	nd	8.57	11.42	17.78
Mean by depth		--	7.38	11.83	18.06

Source: Takyi et al. 1977
Notes: nd -- not determined
S_o = original mix (check)
S_1 = 5.29 mmho/cm at initiation of experiment
S_2 = 9.52 mmho/cm at initiation of experiment
S_3 = 18.73 mmho/cm at initiation of experiment
Na_2SO_4 was used to salinize the pots.
[a] for alkali grass, creeping red fescue, and alfalfa

Table 16.28. pH and salinity of the tailings sand-peat-overburden mix (Fort McMurray Alberta, Oil Sands) adjusted with Na_2CO_3 and H_2SO_4.

	pH level A	pH level B	pH level C	pH level D
Desired pH	3.50	5.00	7.00	9.50
Adjusted pH (after 48 hrs. equilibration)	3.40	5.10	7.50	9.62
pH at harvest (1st seeding)	6.56	7.05	7.64	10.50
pH at harvest (2nd seeding)	6.56	6.76	7.06	10.12
Electrical conductivity (mmho/cm)	4.00	2.92	2.03	14.15

Source: Takyi et al. 1977.

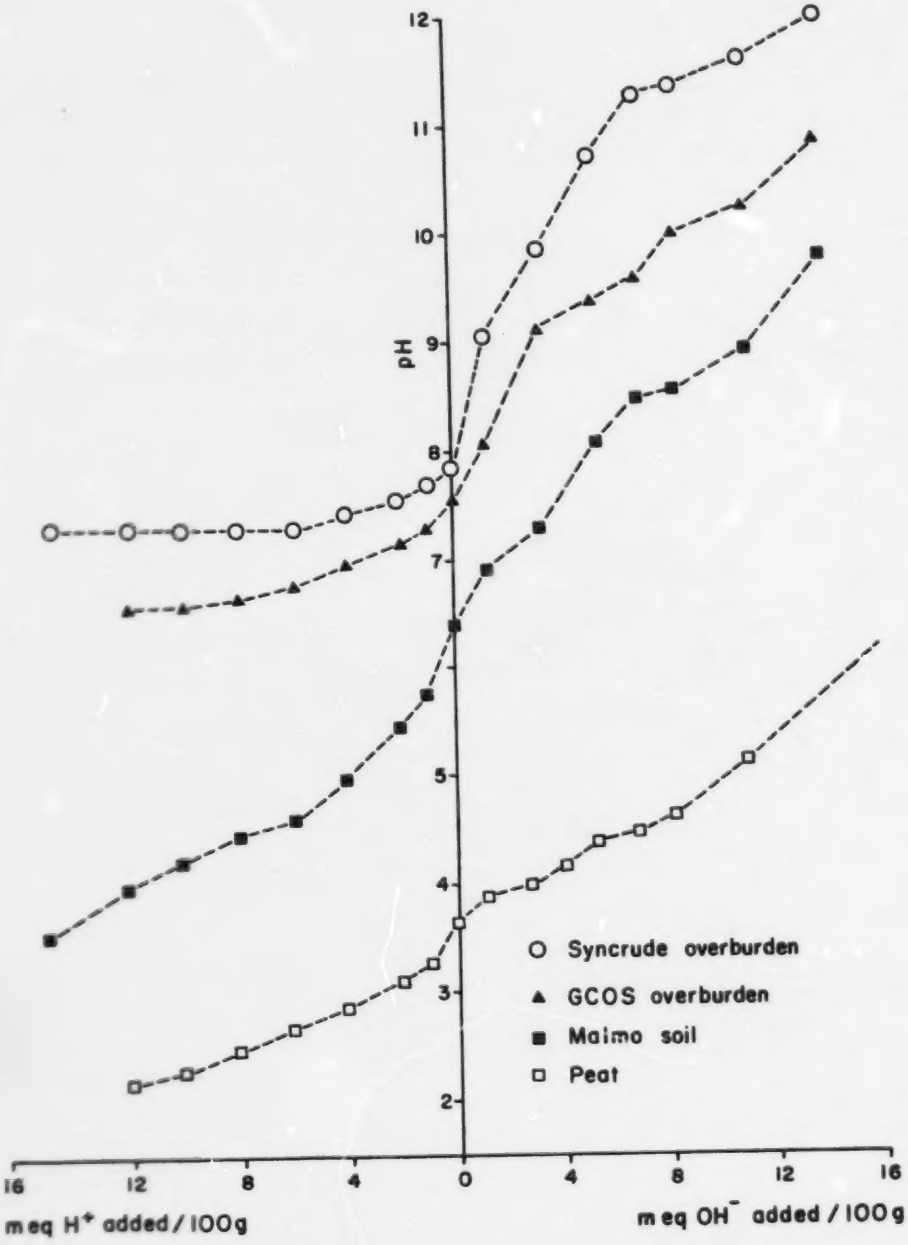

Figure 16.4. Buffering capacities of an acid peat, an agricultural soil and overburden materials.

Source: Takyi et al. (1974)

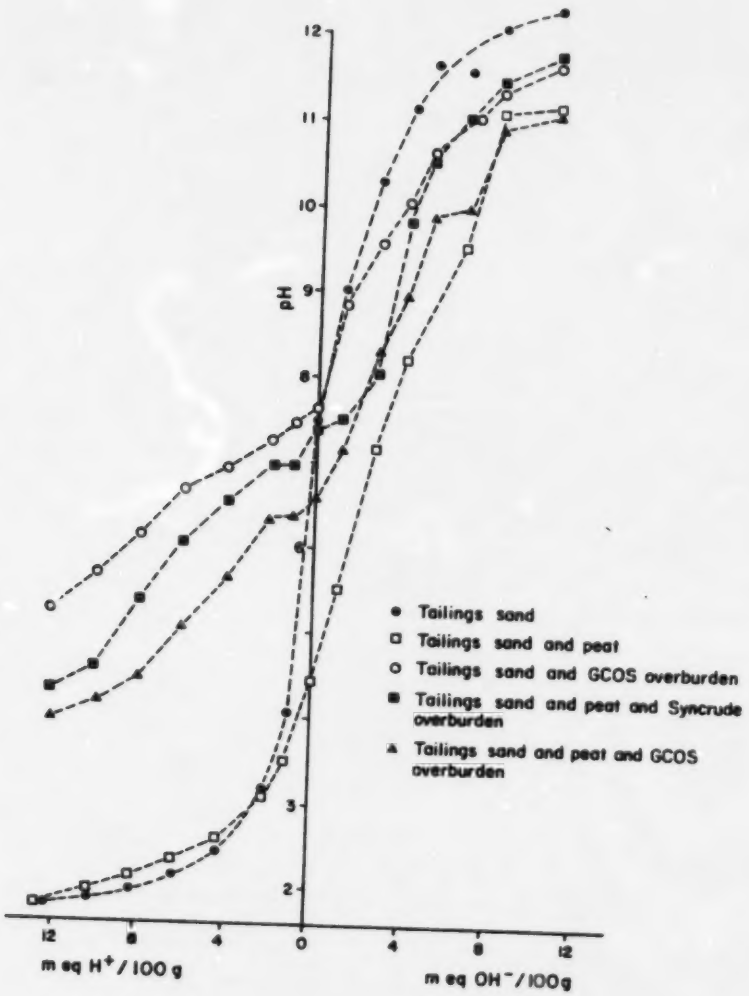

Figure 16.5. Buffering capacities of tailings sand and tailings sand soil mixes.

Source: Takyi et al. (1974)

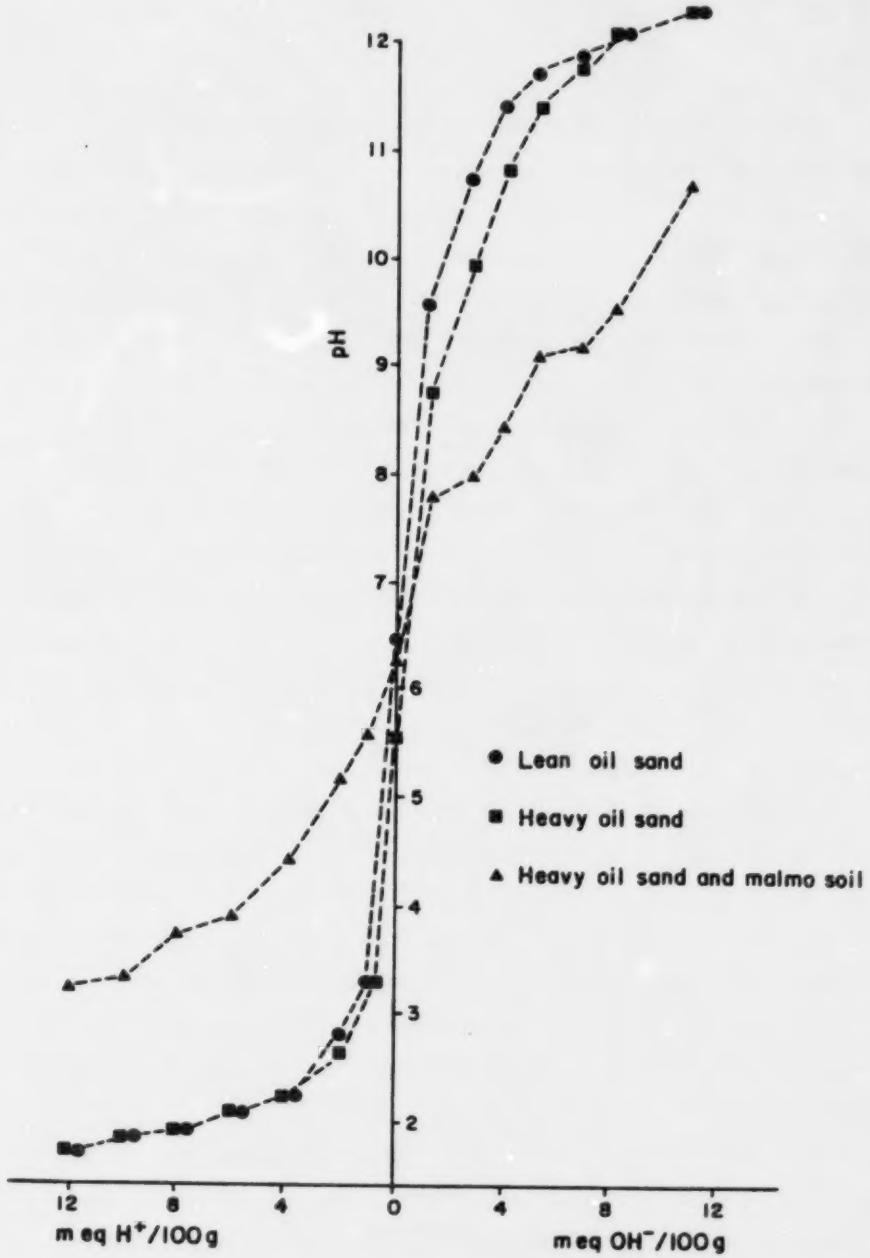

Figure 16.6. Buffering capacities of lean and heavy oil sands and a heavy oil sand-Malmo soil mix.

Source: Takyi et al. (1974)

16.6). It is obvious that the peat is the best buffered (Figure 16.4) while the tailings sand and oil sands are the least buffered (Figures 16.5 to 16.6). The overburden used was well buffered against acidification but less buffered against salinization (both responses are due to partially sodic overburden). The agricultural Malmo soil was moderately well buffered. As expected mixing tailings sand with peat and overburden produced intermediate buffering capacities.

The microbial population and activity levels of various soil-sand mixes were also studied. Considerable detailed results are presented by Takyi et al. (1977) including information on nitrogen fixation, enzyme activity, denitrification, sulfate reduction, bacteria, fungal and algal population levels, and carbon dioxide soil respiration. Only the latter are reported here (Table 16.29). Soil respiration of CO_2 is often used as a measure of overall soil productivity and biological activity. Thus the results shown in Table 16.29 illustrate the very large range in productivity between the materials surveyed.

According to these data, peat would be the most productive followed by Malmo soil, with tailing sand oil and sands being the least productive. Mixing low and high productive materials has some unexpected results. Mixing peat and tailings sand has apparently little effect on tailings sand productivity, whereas mixing Malmo soil and heavy oil sand increases the CO_2 evolution seven times over the sands original productivity. Mixing peat, tailings sand, and overburden has intermediate effects.

Since agricultural soils are generally not available for tailing or oil sands reclamation, these results suggest peat-overburden-sand mixtures would be the most biologically productive.

Fertilization studies using the same growth chamber techniques showed similar results (Table 16.30). Although nutrient levels were significantly higher and Na levels lower in the peat-sand mix than peat-overburden mix, pH was too low in the unlimed peat-sand mix for optimum plant growth. As expected, liming this peat-sand mix very markedly reduced NH_4 and available P levels with significant losses of K and SO_4 as well (Table 16.30).

Table 16.29. Carbon dioxide production from untreated soils and oil sand mixes.

Material	CO_2 rate ug CO_2-C/h/100 g air-dry soil*
GCOS Peat	72.5
Tailings Sand	7.5
Malmo Soil	25.5
GCOS Overburden	24.6
Syncrude Overburden	16.7
Heavy Oil Sand	7.5
Lean Oil Sand	3.4
Peat + Tailings Sand	7.5
Malmo + Heavy Oil Sand	52.5
Peat + Tailings Sand + GCOS Overburden	26.7
Peat + Tailings Sand + Syncrude Overburden	29.6
Tailings Sand + GCOS Overburden	17.5

Source: Takyi et al. 1977.
* Heavy tar sand was field moist, peat was partially air dried.

Table 16.30. pH, salinity and nutrient levels of each soil mix for each fertility treatment of the second seeding, at Fort McMurray, Alberta.

	Tailings Sand				Tailings Sand:Peat(1:1)			
	Nil	NPKS	NPKS + Micro	NPKS + Micro + Lime	Nil	NPKS	NPKS + Micro	NPKS + Micro + Lime
pH	7.43	6.45	6.35	8.34	4.29	4.41	4.42	7.45
Conductivity (mmho/cm)	0.44	0.55	1.03	0.37	0.38	0.41	0.48	1.23
NH_4^+ ppm	1.53	1.43	1.53	0.70	1.44	14.69	12.43	1.45
NO_3^- ppm	0.78	1.32	1.05	11.20	0.86	5.98	9.31	3.32
NH_4^+ plus NO_3^- ppm	2.31	2.75	2.62	11.90	2.30	20.67	21.74	4.77
P ppm	3.48	6.01	5.68	5.02	2.89	6.72	6.58	5.26
K ppm	22.0	55.0	58.0	73.7	28.0	86.3	120.7	69.5
SO_4 - S ppm	20.20	17.80	21.10	38.50	53.35	30.00	39.50	16.25
Na ppm	76.5	66.0	65.0	79.3	72.3	69.5	80.2	90.0

	Sand:Overburden(1:1)				Tailings Sand:Peat:Overburden(2:1:1)				Agricultural Soil (Malmo)			
	Nil	NPKS	NPKS + Micro	NPKS + Micro + Lime	Nil	NPKS	NPKS + Micro	NPKS + Micro + Lime	Nil	NPKS	NPKS + Micro	NPKS + Micro + Lime
pH	8.01	7.79	7.73	8.11	7.61	7.30	7.26	7.87	6.16	5.99	5.94	7.65
Conductivity (mmho/cm)	1.23	1.34	1.06	1.29	0.51	0.73	0.76	0.78	0.17	0.24	0.20	0.45
NH_4^+ ppm	0.18	0.48	0.05	0.07	0.11	0.09	0.05	0.18	0.29	0.53	0.38	0.26
NO_3^- ppm	0.11	0.08	0.21	0.09	0.18	0.10	0.37	0.44	0.22	0.19	0.34	0.30
NH_4^+ plus NO_3^- ppm	0.29	0.56	0.26	0.16	0.29	0.19	0.42	0.62	0.51	0.72	0.72	0.56
P ppm	2.32	5.38	5.24	3.60	2.63	4.97	5.37	3.57	1.49	4.23	4.38	2.18
K ppm	35.7	68.7	61.5	71.0	32.5	43.0	48.0	43.5	103.7	141.5	133.2	131.0
SO_4 - S ppm	70.35	78.10	77.20	75.00	31.90	59.05	58.45	58.50	4.45	11.55	9.25	21.85
Na ppm	77.5	76.7	77.2	80.0	65.5	71.2	76.2	6.60	4.60	48.5	47.2	57.2

Source: Takyi et al. (1977)

By the second seeding, yields of grass legume mixtures (see Table 16.31) tended to follow the pattern of CO_2 respiration (Table 16.29) rather than the soil nutrient levels (Table 16.30). The Malmo soil had the highest yields followed by tailings-peat-overburden mix and tailings-overburden mix with tailings sand-peat mix and tailings sand alone tending to have the lowest yields (Table 16.31). These results suggest that the biological productivity may be more important and limiting than the nutrient levels.

The limitations of this work, however, should be kept in mind. Since the experiments were done with disturbed, usually air dried materials, and with pots in growth chambers, it is not easily extrapolated to the field situation. Thus these results provide some information on biological activity, nutrient levels, and yield conditions when other conditions are ideal. The most masked in situ difference is probably extended soil moisture stress according to R.J. Fessenden of the Alberta Research Council (personal communication, 1982).

Some in situ research has been done and that of Fedkenheuer (1979) has addressed both nutrient and moisture availability. In an off site in situ experiment, soils were reconstructed over tailings sand with various combinations of mineral fines (clay) native sand, lean tar sand, and peat. All plots received an initial blanket fertilization of 50:50:50 kg/ha of NPK. Subsequently plots were either fertilized annually at this rate or not fertilized.

As Table 16.32 shows the peat contributed the most C, N, Ca, and Mg and the least P to the reconstructed soil. The Ca and Mg in the peat are probably from contamination of the peat by underlying calcareous glacial till incorporated during peat salvage. The peat pH values are anomalously high, presumably due to such mineral soil contamination. The initial high level of P in the reconstructed soil is obviously from the initial fertilization as apparently 80 to 90% of it is rapidly leached out after one year (Table 16.32).

If there were no interaction between materials in the 10 cm clay plus 15 cm peat treatments (rotovated to 30 cm depth with tailings

Table 16.31. Dry matter yields of legume-grass mixtures grown on different soil and oil sands mixes as affected by fertilizer and lime. Second seeding.

Soil Mix	Yield (g/pot)[a] Tops + Roots			
	Nil	NPKS	NPKS + Micro	NPKS + Micro + Lime
Tailings Sand	0.96	6.29	6.46	5.24
Tailings Sand:Peat (1:1)	0.50	6.06	5.75	7.12
Tailings Sand:Overburden (1:1)	1.64	8.46	8.37	7.68
Tailings Sand:Peat:Overburden (2:1:1)	1.09	8.34	8.77	8.84
Agricultural Soil (Malmo)[b]	5.23	9.83	10.35	11.74

Source: Adapted from Takyi et al. (1977)

[a] Yield in average of two replicates.

[b] A high percentage of the fine roots in the Malmo could not be recovered.

Table 16.32. Results of analyses for selected chemical characteristics of the base soil materials and the tailings sand amended with these base soil materials Fort McMurray, Alberta.

Soil Material	pH	Total N (%)	Organic C (%)	Avail. P (ppm)	E.C. (mmho/cm)	Exchangeable Cations (meq/100g) Na	K	Ca	Mg
Base Soil Materials									
Peat	7.5	0.36	23.35	0	0.42	0.96	0.23	27.25	8.23
Mineral Fines (Clay)	8.3	0.03	1.15	2	0.40	0.93	0.40	21.20	4.17
Lean Tar Sand	6.3	0.05	4.80	7	1.77	0.33	0.26	2.40	1.57
Native Sand	7.2	0.01	0.25	1	0.27	0.29	0.04	0.45	0.15
Tailings Sand	7.5	0.01	0.20	11	0.24	0.25	0.08	1.35	0.77
Amended Tailings Sand[a]									
10 cm Native Sand									
1977	7.3	0.19	3.77	33	0.79	0.28	0.12	12.61	1.78
1978	7.3	-	-	7	0.51	0.34	0.08	14.54	2.37
10 cm Lean Tar Sand									
1977	7.3	0.15	5.03	25	1.41	0.35	0.15	10.87	2.58
1978	7.1	-	-	5	0.82	0.36	0.11	18.64	3.17
10 cm Mineral Fines									
1977	7.3	0.19	4.01	47	0.92	0.54	0.18	18.18	3.40
1978	7.4	-	-	5	0.50	0.60	0.16	28.05	4.05
20 cm Mineral Fines									
1977	7.3	0.15	3.22	33	0.86	0.66	0.21	19.73	3.67
1978	7.3	-	-	7	0.53	0.85	0.20	28.23	4.50

Source: Fedkenheuer (1979).
[a] All treatments include 15 cm of peat.

sand), about 75% of the water holding capacity at 1/3 bar moisture tension would be due to the peat (Table 16.33). Similarly, even in the 20 cm clay plus 15 cm peat treatment, about 61% of the water holding capacity at 1/3 bar should be due to the peat (Table 16.33). In practice of course, interaction occurs, reducing the effectiveness of amendments to increase water holding capacity. In this experiment it appears the overall reduction is to an efficiency of 57% (Table 16.32). Herbage yields showed the expected results of highest yields on 10 and 20 cm clay plus 15 cm peat (Table 16.34). The 10 cm plus 15 cm peat shows the highest legume yield, presumably due to the highest available N levels (i.e., the peat, the principal N source, is diluted less with clay). Fertilizer appeared to supress yields though no explanation was given.

Detailed research on nutrient cycling has been undertaken by Rowell (1978, 1979) on tailings sand dikes at Suncor. The experimental design incuded three annual fertilizer application rates:

1. 80, 35, 75 and 20 kg/ha of NPKS;
2. 150, 40, 150 and 20 kg/ha of NPKS; and
3. 300, 80, 300 and 40 kg/ha of NPKS; and

secondly, eight soil reconstruction amendment formulas:

1. peat tilled to 15 cm depth;
2. same as (1) with contour trenches;
3. same as (1), plus "Aquatain" soil stabilizer on surface;
4. same as (1) plus "bitumus" soil binder on surface;
5. 5 cm (750 t/ha) overburden added on surface of peat;
6. 10 cm overburden tilled in with peat;
7. 5 cm overburden tilled in with peat; and
8. same as (1) except left bare for one year.

The peat was a blanket application over the whole plot area. Unfortunately the designed layer thickness of 15 cm peat was not uniformly achieved and actual peat thickness varied from 7 cm to 25 cm. Extra peat, different in nature from the original, was added to the thinnest peat layer areas in an attempt to compensate for this

Table 16.33. Results of analyses for selected physical characteristics of the base soil materials and the tailings sand amended with these base soil materials (collected in 1977) Fort McMurray, Alberta.

Soil Material	Moisture Content (%) 1/3 bar	15 bars	Available Water (%)	Particle Size Analysis (%) Clay	Silt	Sand
Base Soil Materials						
Peat	88.8	52.6	36.2	6	24	70
Mineral Fines (Clay)	25.9	13.6	12.3	49	14	37
Lean Tar Sand	12.5	4.4	8.1	6	23	71
Native Sand	1.3	0.6	0.7	1	2	97
Tailings Sand	3.5	1.3	2.2	4	5	91
Amended Tailings Sand[a]						
10 cm Native Sand						
Fertilized	15.3	9.0	6.3	2	9	89
Unfertilized	15.5	8.7	6.8	2	9	89
10 cm Lean Tar Sand						
Fertilized	21.8	13.3	8.5	6	19	75
Unfertilized	17	8.8	8.2	5	17	78
10 cm Mineral Fines						
Fertilized	29.8	16.2	13.6	16	14	70
Unfertilized	22.3	11.5	10.7	17	11	72
20 cm Mineral Fines						
Fertilized	26.3	13.5	12.8	25	15	60
Unfertilized	27.7	13.8	13.9	18	14	68

Source: Fedkenheuer (1979)
[a] All treatments include 15 cm of peat.

Table 16.34. Air dry weight of herbage produced in 1978 on amended tailings sand plots, Fort McMurray, Alberta.

Soil Amendment[a]	Plant Top Weight (kg/ha) Grasses	Legumes	Total
10 cm Native Sand			
Fertilized	4 748	60	4 808
Unfertilized	5 282	12	5 294
10 cm Lean Tar Sand			
Fertilized	2 612	58	2 670
Unfertilized	262	148	410
10 cm Mineral Fines			
Fertilized	3 198	26	3 224
Unfertilized	3 860	128	3 988
20 cm Mineral Fines			
Fertilized	3 676	14	3 690
Unfertilized	4 176	74	4 250

Source: Fedkenheuer (1979).
[a] All treatments include 15 cm of peat.

variability. Plots were 5 x 4 m with three replicates for each treatment.

Balance sheets were constructed for major nutrient species and elements including leaching and runoff losses. From these results nutrient cycling was estimated. Figure 16.7 (Rowell 1979) summarizes much of this data for nitrogen. It is important to note that from 40 to 100% of mineral N comes from peat, depending upon fertilization rate. Thus peat is always an important source of nitrogen and probably the major sustained source. Peat has the potential to provide much of the N required for plant uptake. Litter and other sustained sources (not including fertilization) provide only about one-third of plant N requirements.

The N losses are also interesting. Denitrification is the largest loss despite the predominant sand textures (which one would expect would produce an aerobic denitrification limiting soil), low rainfall, and low winter temperatures. Leaching is the next most significant loss, with runoff losses being insignificant. [Rowell did not include volatilization of N in Figure 16.7]

Less data are available on P, K and S cycling on reconstructed dike soils. It is assumed P is relatively immobile and indications are that up to around 20 kg/ha/a are released from the organic complex and up to 14 kg/ha/a are absorbed in plant uptake. The largest potassium flux is probably leaching at 1 to 10 kg/ha/a. At low levels K leaching may exceed N leaching losses. Similarly, large SO_4 leaching losses may occur (i.e., up to 40 kg/ha/a). Since overburden tends to be S rich the risk of S deficiency due to leaching is low.

Only one brief paper on peat utilization for soil reconstruction in the Plains region was found. In what was essentially a topsoil study, McAllister Environmental Services Ltd. (1978) added 15 cm of peat to a soil wedge experiment on spoil at the Highvale Mine near Edmonton. The soil wedge was from 0 to 1 m thick. The peat used appeared as effective as the Wabamun Clay and Modeste Sandy Loam. Detailed results, however, were not reported.

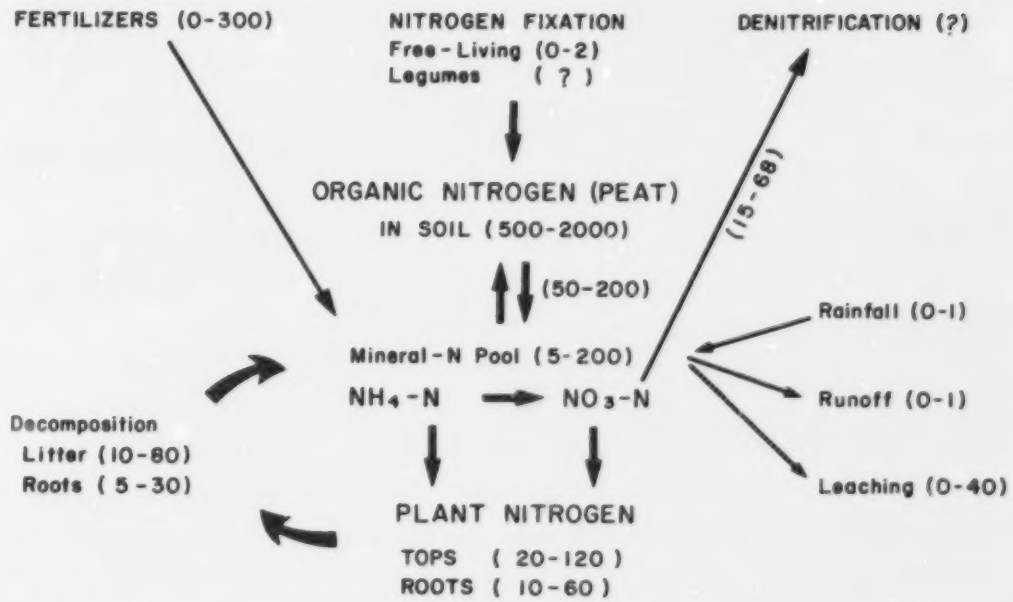

Figure 16.7. Cycling of nitrogen on a Suncor tailings dyke amended with peat, overburden and fertilizers and seeded in 1976.

Source: Rowell (1979)

16.5 SUMMARY

Amendments to spoil can improve nutrient status, mask or buffer toxicity, increase cation exchange capacity, increase moisture retention, improve structure, improve aeration, improve organic matter accumulation, and increase flora and fauna.

Mulches generally improve temperature and aeration, decrease runoff, increase infiltration, increase snow catch, and decrease erosion. Mulches may also have an unfavourable effect on temperature and increase rodents, weeds, and disease and insect pests.

The use of mulches depends upon availability, cost, and desired effect. These factors vary considerably with different materials. Straw and hay may be the most cost effective with the least inherent problems.

Soil stabilizers are generally used to reduce erosion and stabilize slopes. Numerous types are available and costs are often high. Use of stabilizers may delay vegetation establishment; gas and water permeability of the soil crusts formed varies considerably and is very important. Combining stabilizers and mulches may be a cost effective treatment.

Soil conditioners are generally added to enhance physical or chemical properties. Derivatives of peat have been used to supply fertilizer while at the same time increasing soil aggregation and moisture retention and decreasing hydraulic conductivity and leaching. Liming is a generally recommended treatment for improving (raising) soil pH.

Topsoiling is generally most effective as a surface amendment. Incorporating topsoil into spoil may decrease the beneficial effect. Topsoiling can improve all chemical and physical properties of reclaimed areas. Improved infiltration produced by topsoiling increases leaching of toxic ions from underlying spoil. Research is ongoing to determine depths of topsoil and till required to prevent salt migration from spoil into the root zone. Materials such as bottom ash and gypsum are being studied as possible buffers to salt migration. Past research in this area has generally been inconclusive.

Peat is an excellent soil amendment where available. Peat improves spoil structure without adding toxic elements or pathogens that may be contained in sewage or manure.

Mixing peat with spoil is better than adding it as a surface amendment (in contrast to topsoil). Peat provides a buffer capacity to coarse spoils, improves moisture status, and provides certain essential elements and of course, organic matter. In the oil sands, peat, overburden, and tailings sand mixes are most biologically productive, but optimum amounts, mixing depth, and biological stability of the soil system formed have not yet been determined.

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17. FERTILIZERS

This chapter discusses fertilizers in terms of enhancement of soil chemical and nutrient status. Considerable research has been carried out on fertilization directed primarily at initial vegetation establishment. This is discussed in Chapters 35 and 40.

17.1 SOURCES

In coarse textured spoils such as sands and gravels, where plant toxicity is often not a problem, plant nutrient deficiencies frequently are a problem (e.g., Zimmerman and Moore 1976). Phosphorus and potassium are easily supplied by fertilization since they tend to be retained in the soil. Nitrogen, however, is easily lost from the soil-plant system.

Sheard (1976) stated that slow release fertilizers are preferred on coarse textured reclamation sites to minimize nutrient loss by leaching. Ideally nutrients are released at the same rate as the rate of plant nutrient uptake. Slow nutrient release can be achieved by chemically binding the nutrients in compounds that break down slowly. Fertilizers can be incorporated in pellets within semi-permeable membranes or chemically inert materials. The chemical properties of some nitrogen carriers are presented in Table 17.1 (Sheard 1976).

Attributes and limitations of reactions in the soil are as follows:

1. Urea-formaldehyde:
   - nitrogen release is not influenced by granule size
   - rate of release is slightly greater in acid conditions
   - nitrogen release is limited at soil temperatures less than 15°C
2. Crotonylidene Diurea (CDU) and Isobitylidene Diurea (IBDU). Both CDU and IBDU are nitrogen carriers with the following properties:
   - rate of release increases with decreasing granule size, lowering pH, and increasing soil temperature and soil moisture

Table 17.1. Properties of some nitrogen carriers.

Carrier	Chemical Form	Nitrogen Concentration (%)	Solubility in Water (g/100 mL)
Urea-formaldehyde (U.F., Ureaform)[a]	Organic	38	Trace
Crotonylidene Diurea (C.D.U., Floramid)[a]	Organic	32	0.12
Isobutylidene Diurea (I.B.D.U.)[a]	Organic	32	0.01
Blood Meal	Organic	13	0
Activated Sewage Sludge	Organic plus NH_3	5 to 6	Trace
Sulphur Coated Urea (S.C.U.)[a]	Inorganic	32	20[b]
Metal Ammonium Phosphates	Inorganic	8[c]	0.05
Urea	Inorganic	46	100
Ammonium Nitrate	Inorganic	34	100

Source: Sheard (1976).
[a] Synonymous terms.
[b] In seven days at 38°C
[c] "Mag-Am P" analysis of 8-40-0-14 (Mg)

- release of nitrogen from IBDU is thought to be from hydrolysis of the molecule rather than by microbial action.

Neither CDU or IBDU are commercially available in Canada.

3. Activated sewage sludge and bone meal: Both materials have limited commercial application due to high costs.
4. Liquid sewage sludge:
   - may have some value where transportation costs can be minimized
   - may result in heavy metal build-up in soils
5. Sulfur-coated urea (SCU):
   - urea granules coated with molten sulfur
   - cracks in cooling sulfur sealed with wax
   - nitrogen released by microbial breakdown of wax
   - rate of release controlled by thickness of coating, type of wax, inclusion of biocides, soil temperature, and soil moisture
   - SCU is produced on a commercial scale by Canadian Industries Limited
6. Metal ammonium phosphates (Mg, Fe):
   - slow release properties due to low water solubility of the inorganic molecule
   - rate of release increases with decrease in granular size
   - material has additional advantages where phosphorus and magnesium are required as plant nutrients
   - cost of material is prohibitive to large-scale commercial application

Another unconventional source of plant nutrients was investigated by Moschopedis (1974). Sulfomethylated humic acid was prepared from coal and compared to NH_4, SO_4, and NH_4NO_3 fertilization at equivalent rates of N (Table 17.2). The humic acids gave superior results, probably due to additional sulfur. Phalaris arundinacea on

Table 17.2. Quantities of elements added at different humate application.

Element	Humate Application Rate		
	714 kg/ha	3659 kg/ha	7138 kg/ha
Ca	34.1	174.7	340.8
Mg	13.0	66.6	129.9
Na	2.6	13.4	26.1
K	1.6	8.0	15.7
N	16.0	81.8	159.5
P	0.9	4.5	8.9
Zu	0.07	0.35	0.07
Cu	0.004	0.020	0.040
Mn	0.16	0.84	1.64
Fe	0.50	2.56	5.00
As	0.001	0.004	0.007
Se	0.0001	0.0002	0.0003
Cation exchange capaciaty (meq/m^2)	16.1	82.7	161.3

Source: Moschopedis (1974).

spent Athabasca tar sands showed an initial significant growth response to all forms of N fertilization, including sulfomethylated humates. This is also discussed in Chapter 16.1.2.

17.2 FERTILIZER YIELD RESPONSES

In sodic spoils significant positive response to N and P combined has been reported yet with little response to N and P individually and to micronutrients (Table 17.3; Sandoval et al. 1973). The same authors reported differing fertilizer responses for lignite strip mine spoils in the Northern Great Plains. Yields showed no response to N fertilization alone and yet an order of magnitude response to P fertilization (Table 17.4).

In near neutral spoils Bauer, Berg and Gould (1978) reported some yield response to P fertilization which in this instance they stated could be correlated with measurements of available P. However their data suggest the yield response was primarily due to increased topsoil thickness (Table 17.5).

The reports on the efficiency of topsoil and gypsum amendments for these same soils are variable and somewhat contradictory. For example there was little yield response to gypsum or topsoil amendments at high fertilization rates in lignite spoil (Table 17.4). Conversely in near neutral spoils, the authors reported marked yield responses to increasing topsoil thickness at all fertilization rates. As Table 17.5 illustrates, 30 cm of topsoil and 34 kg/ha P was sufficient to obtain maximum yield with about one third of the yield increase over the control due to fertilization and two thirds of the yield increase due to the topsoil.

Work in the U.K. on PO_4 adsorption on acid shale coal mining waste (Pulford and Duncan 1975; Doubleday 1972) could have relevance to similar materials in the Peace River and Forestburg areas. It is well known that PO_4 sorption in soil environments is a function of Fe, Al, Ca, and SO_4 present (Tables 17.6 and 17.7; Pulford and Duncan 1975). In these studies P sorption was essentially indirectly controlled by pyrite oxidation and the resultant Fe adsorption sites which were formed.

Table 17.3. Response of barley plants grown in a growth chamber on upper and lower mantles of the overburden to nitrogen, phosphorus and minor elements, Northern Great Plains.

	Total Dry Matter (g/can)	
Fertilizer	Upper Mantle	Lower Mantle
None	4.6	1.4
Nitrogen (100 ppm)	4.3	0.8
Phosphorus (400 ppm)	7.2	5.4
Nitrogen and Phosphorus	16.1	21.1
N & P & microelements[a]	17.4	22.5

Source: Adapted from Sandoval et al. (1973).
[a] Microelements - Mn, 1.8 ppm; Zn, 10 ppm; Cu, 0.16 ppm; Fe, 5 ppm.

Table 17.4. Total dry matter production (lbs/ac) or sprinkler irrigated barley on smoothed strip mine spoil piles, North Dakota, 1971.

	N and P fertilizer (lb/ac)			
Amendment	0-0	200-0	0-200	200-200
Check	175	200	2305	2320
Gypsum[a]	190	140	2790	2450
Topsoil[b]	260	190	2040	1585
Topsoil plus Gypsum	260	290	1985	1690

Source: Adapted from Sandoval et al. (1973).
[a] 3 t/ac, disced in
[b] 5 to 7 cm mixed with spoil plus 5 cm of unmixed topsoil on top.

Table 17.5. Spring wheat grain yield on coal mine spoil in North Dakota as affected by fertilizer P rate[a] and topsoil thickness, 1975.

	Yields of grain (kg/ha)			
	Topsoil, cm			
P(Kg/ha)	5	10	30	60
0	120	168	197	283
34	96	119	297	230
101	95	148	264	256

Source: Adapted from Bauer, Berg and Gould (1978).
[a] broadcast, in addition to P drilled at 34 kg/ha on all treatments.

Table 17.6. Physical and chemical properties of English acid coal spoil.

	Black + Red shales		Black shale		Red shale	
	Range	Mean	Range	Mean	Range	Mean
Phosphate adsorption mg P/100 g	0.45 to 12.65	5.8	2.20 to 12.65	6.8	0.45 to 10.35	4.9
Tamm Fe mg Fe/100 g	13.0 to 306.8	128.7	63.0 to 306.8	175.4	13.0 to 181.8	85.0
Tamm Al mg Al/100 g	12.1 to 236.0	70.3	23.7 to 106.6	48.0	12.1 to 236.0	91.2
Tamm Al + Fe mg Al + Fe/100 g	36.7 to 392.5	199.4	101.7 to 370.7	224.1	36.7 to 392.5	176.2
pH	3.45 to 8.08	6.2	3.45 to 7.88	5.9	4.18 to 8.08	6.5
% < 2mm	26 to 81	48	26 to 81	50	26 to 73	46
Acetic soluble SO_4^{-2} me SO_4^{-2}/100 g	0.3 to 29.0	13.6	0.3 to 28.8	9.9	3.5 to 29.0	18.3
Acetic soluble Ca me Ca/100 g	5.0 to 105.4	36.2	5.0 to 74.8	30.6	7.4 to 105.4	41.4

Source: Pulford and Duncan (1975)

Table 17.7. Correlation coefficients (r) between phosphate adsorption and other properties of English acid coal spoil.

	Total samples				
	Black + Red	Black	Red	Stoneyburn	North Lodge
Tamm Fe	0.81***[a]	0.85***	0.79***	0.94***	0.80***
Tamm Al	0.91	0.19	0.48	-0.48	0.14
Tamm Al + Fe	0.81***	0.84***	0.77***	0.97***	0.80***
pH	-0.23	-0.70**[b]	+0.31	-0.33	-0.32
% < 2 mm	0.29	0.24	0.32	-0.06	+0.13
Acetic soluble sulphate	-0.52	-0.41	-0.46	-0.33	-0.86**
Acetic soluble calcium	-0.42	-0.74**	-0.17	-0.48	-0.13

Source: Pulford and Duncan (1975)

[a] *** = denotes significant at the 0.1 per cent level.

[b] ** = denotes significant at the 1 per cent level.

Heating the black shale beyond 400°C, which frequently occurs naturally, converted it to red shale, crystallizing the amorphous Fe present and thereby reducing PO_4 adsorption by about 40% (Table 17.6). This suggests that in reclaiming such shale material, black shale should be covered where possible with red shale to reduce fertilizer P fixation.

In the oil sands area yield responses to fertilization and amendments in the reconstructed soils were more predictable. As expected the infertile coarse textured overburden and tailings sands, with minimal cation exchange capacity, moisture retention and structure, showed marked positive yield responses to fertilization and amendments. Studies on Suncor (GCOS) tailings sand and overburden showed positive yield responses (Hordeum vulgare and Medicago sativa) to NPK, S, peat, and sewage sludge, but no positive response to micronutients (Tables 17.8, 17.9, 17.10; McCoy, Regier and Graveland 1976). The only micronutrient response was a marked yield supression caused by trace fertilization with B (Table 17.8). Note that the yield supression does not occur when boron is removed from the total trace amendment.

Dancer (1975) developed an empirical model for calculating the maximum N fertilization rate for coarse textured spoils in Cornwall, U.K., which with minor modifications could be applied to the coarse textured tailings sands and overburden in the Oil Sands area. Since leaching dominates the N fertilization cycle in these materials the model calculates the depth to which NO_3 is leached as follows:

$$c = CoXo\ (2Bx_m)^{\frac{1}{2}} \exp - (x - x_m)/2\ x_m \qquad (1)$$

$$Cmax = CoXo\ (2Bx_m)^{-\frac{1}{2}} \qquad (2)$$

where Co is the initial NO_3 concentration near the soil surface to a depth of Xo

X_m is the soil depth where NO_3 is a maximum

B is the dispersion coefficient for NO_3

Table 17.8. Mean barley yields (g) in tailing sand in vitro from spent Alberta oil sands greenhouse experiment.

Treatment	Mean Yield* g
1. NPK + S	1.8 a[c]
2. NPK	1.6 a
3. NPK + Tr[a]	0.7 d
4. NPK + (Tr - B)[b]	1.6 a
5. NPK + (Tr - Zn)	1.2 bc
6. NPK + (Tr - Cu)	1.2 bc
7. NPK + (Tr - Mg)	1.1 c
8. NPK + (Tr - Mn)	1.1 c
9. NPK + (Tr - Mo)	1.1 c
10. NPK + (Tr - Ca)	1.0 c
11. NPK + (Tr - Fe)	1.0 c

Source: McCoy, Regier and Graveland (1976).

[a] Tr = B + Zn + Cu + Mg + Mn + Mo + Ca + Fe

[b] Tr - B = Zn + Cu + Mg + Mn + Mo + Ca + Fe

[c] Means followed by the same letter do not differ significantly from one another (P = 0.05). Duncan's New Multiple Range Test.

* Dry matter content.

Table 17.9. Mean barley yields g[a] in tailing sand and overburden materials in vitro.

Spent sand

	0	P_1	P_2
0	0.2	0.7	0.8
F_1		4.3	6.5
F_2		7.3	10.4

Overburden (waste dump)

	0	P_1
0	0.5	0.5
F_1		4.7
F_2		8.5

80% Spent sand and 20% Overburden

	0	P_1
0	0.6	0.6
F_1	4.8	5.3
F_2	6.1	7.9

20% Spent oil sand and 80% overburden

	0	P_1
0	0.5	0.5
F_1	4.5	5.5
F_2	7.8	9.0

P_1 Decomposed peat 20% by volume
P_2 Decomposed peat 40% by volume
F_1[b] 50 mg/kg N, 30 mg/kg P, 38 mg/kg K
F_2 100 mg/kg N, 60 mg/kg P, 76 mg/kg K

Source: Adapted from McCoy, Regier and Graveland (1976)

[a] Dry matter content.

[b] Fertilizer application rates based on mineral portion (1400 g).

Table 17.10. Mean barley yield (g) in amended tailings sand and peat from Fort McMurray, Alberta (in vitro).

Treatment	Mean Yield[1] Crop 1	Mean Yield[1] Crop 2
(a) Spent Sand (1210g) + Sludge (130g) + NPK[2] [3]	5.0 a[4]	3.3 a
(b) Spent Sand (1210g) + Sedge (50g) + NPK	4.8 a	1.1 c
(c) Spent Sand (1210g) + Peat (160g) + NPK	3.3 c	1.5 c
(d) Spent Sand (1210g) + Sphagnum (30g) + NPK	1.1 e	1.3 c
(e) Sedge (255g) + NPK	2.2 d	0.0 c
(f) Peat (450g) + NPK	3.9 b	2.4 b
(g) Sphagnum (105g) + NPK	0.5 f	1.2 c
(h) Spent Sand (2100g) + NPK	2.4 d	1.3 c
(i) Spent Sand (2100g) + N_2PK[5]	2.6 d	2.2 b

Source: McCoy, Regier and Graveland (1976).

[1] Dry matter content.

[2] NPK rates (kg/ha) 150 N, 100 P, 126 K

[3] The sewage sludge used had a nitrogen content of 2.44% (approximatley 30% of which was in a readily available NH_4-N form), a phosphorus content of 0.21% (approximately 70% of which was in an orthophosphate form) and a potassium content of 0.23%.

[4] Means in each column, followed by the same letter do not differ significantly (P = 0.05). Duncan's New Multiple Range Test.

[5] N_2PK rates (kg/ha) 300 N, 100 P, 126 K

In the example tested virtually all the NO_3 was leached below the rooting zone in one month (Figure 17.1). In this example no more NO_3 should be applied than can be assimilated in one month, and several seasonal applications are warranted.

Davidson (1974) collected many samples from about 80 spoil piles from underground Pennslyvania coal mines to study herbage response to fertilization with 1120 kg of 10-10-10 per hectare and liming at 11 t/ha and fertilization and liming at these rates combined (Table 17.11). Yield was increased by liming and further increased by fertilization combined with liming (Table 17.11). The author concluded that such lime and fertilizer combinations would produce satisfactory grass cover.

Conversely, Bengtson et al. (1973) found that liming did not increase Pinus taeda seedling growth in experiments on reclaimed spoil in north-eastern Alabama. The experiment used singly, nutrient deficient cultures, lime, and compost (Table 17.12). The authors concluded that spoil N and P deficiencies could be detected and corrected, ensuring adequate plant nutrition. At seeding time N-P fertilization of 56 kg ha/N was recommended in order of preference: (1) ammonium polyphosphate, (2) monoammonium phosphate, and (3) diammonium phosphate. However if fertilization can de delayed by as much as 30 days or if the seeding rate can be increased by 20%, there is no preferred fertilizer form, except in so far as cost is concerned.

In laboratory studies on New Mexico coal mine spoils, Aldon, Springfield and Garcia (1975) found that a 10-5-5 fertilizer at 0, 560, and 1792 kg/ha increased yields of Secale montanum, whereas added bark depressed yields. The effect of bark, which for example shortened leaves, was minimized by fertilization.

At Colstrip, Montana, Meyn, Holechek and Sundberg (1975) reported 56 kg/ha P_2O_5 was sufficient for first year needs; however, long-term fertility and stability problems were not addressed.

In summarizing they suggested the following areas where more research is required: (1) long term fertility requirements, (2) soil-

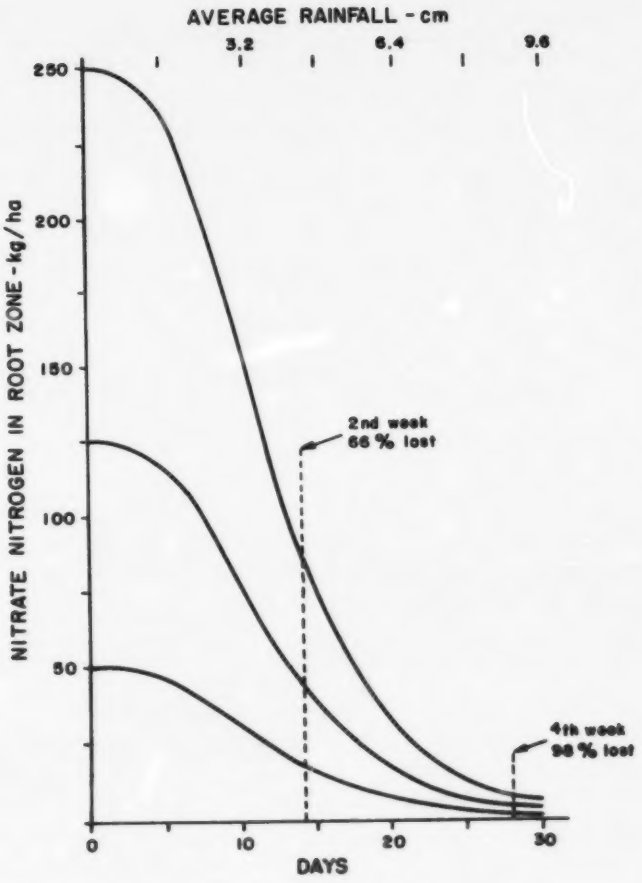

Figure 17.1. Estimated leaching of nitrate from sandy Cornish spoil during a month of average rainfall after treatment with $NaNO_3$ at rates of 50, 125, and 250 kg/ha -N.

Source: Dancer (1975)

Table 17.11. Effects of fertilizer and lime on green matter production of grasses grown in Pennsylvania coal spoil in pot experiments.

Green matter yield	% of Total Pots			
	Control	Fertilizer	Lime	Fertilizer & Lime
None	49	62	9	6
Trace to 0.5 g	49	29	60	17
0.6 to 1.5 g	2	3	28	23
1.6 g +	0	6	3	54

Source: Davidson (1974).

Table 17.12. Effects of fertilization, liming and compost on dry matter yields of Pinus taeda seedlings grown in northeastern Alabama coal spoil material.

Fertilizers	Secondary Amendments g dry matter of seedling tops per pot			
	No Lime No compost	Lime	Compost	Lime & Compost
Control	3.3 c	2.8 c	2.9 c	2.7 c
P,K, Micro (-N)	4.0 c	4.6 c	3.1 c	3.1 c
N,K, Micro (-P)	2.1 c	4.1 c	12.1 b	12.4 b
N,P, Micro (-K)	28.3 a	27.0 a	27.0 a	24.5 a
N,P,K, (-Micro)	24.9 a	27.1 a	24.5 a	24.7 a
Complete	26.8 a	26.2 a	25.1 a	24.2 a

Source: Bengtson et al. (1973).
Note: Means followed by the same letter designation are not significantly different at 95% level of probability.

plant cycling of nutrients, (3) differing species nutrient requirements, (4) palatability, and (5) fertilization alternatives.

Further fertilization research must take into account the uniqueness of mine spoil material. Research into spoil analysis techniques, with special reference to levels of exchangeable P, K, NO_3, and NH_4 are necessary. Short-term fertility requirements for initial establishment and growth must be differentiated from long-term fertility requirements for sustained growth and productivity.

Fertilizer requirements can be assessed from overburden analysis; however, field calibration trials are necessary to study plant production in conjunction with other management factors. The long term prescription has not been determined but will depend on the objectives of reclamation or end land use. On range land, the nutrient cycling process should eventually maintain plant growth. The spoil plantings and adjacent undisturbed areas must be analyzed and assessed to determine the period necessary. To know that one has returned cultivated land to its original productivity it is necessary to compare yields on reclaimed land with those on adjacent similar agricultural soils.

17.3 SPOIL-SOIL RESPONSE TO FERTILIZATION

Spoil-soil response to fertilization would include any changes in soil properties induced by continuous fertilization. This would include: (1) nutrient carry over in available forms; (2) changes in organic matter due to accumulation or degradation of biomass; (3) changes in nutrient cycling; (4) changes in soil chemistry; and (5) indirect effects on structure and pedogenetic processes. An example of indirect effects would be structural changes in response to organic matter accumulation causing increased aggregation. Other examples would be increased leaching and illuviation caused by anhydrous ammonia and structural changes caused by sulfur bearing fertilizers.

Unfortunately, little research has been done in soil climates relevant to Alberta on such fertilization effects and their long-term

impact on pedogenesis especially on reconstructed soils over spoils. The existing short-term studies suggest minimal effects.

At Colstrip, Montana, DePuit and Coenenberg (1979) reported on the effects of fertilization on reconstructed soil properties, particularly nutrient levels. Three basic N fertilization rates were used: 37 kg/ha, 74 kg/ha, and 111 kg/ha, representing light, moderate, and heavy application rates (Table 17.13).

The initial reconstructed soil conditions indicate a sandy loam textured, non-saline, non-sodic soil with low levels of exchangeable salts, yet a saline pH (Table 17.14). Low levels of NO_3-N (Table 17.14) and available P (Table 17.15) in the A horizon would suggest crop yield should respond to fertilization in these soils. The levels of available K in the unfertilized soil, while low, should be sufficient. Although NO_3, NH_4, and available P appeared to increase the year following fertilization, most differences were not statistically significant (Table 17.15). After four years, including three of fertilization, minimal effects on soil properties have been detected (Table 17.16). Most properties show no significant change and those changes which are significant are small in magnitude (Table 17.16). Fertilization, particularly at moderate to high rates, induced small increases in NH_4 and available P levels and in the C:N ratio in the A horizon (Table 17.16).

17.4 SUMMARY

Short-term fertilizer requirements must be differentiated from long-term fertility requirements for sustained growth and productivity.

Possible soil property changes induced by continuous fertilization include: (1) carry over of available nutrients; (2) changes in organic matter accumulation; (3) changes in nutrient cycling; (4) changes in soil chemistry; and (5) indirect effects on pedogenesis.

Slow release fertilizers, or periodic applications, are best in coarse soils or where leaching is severe. Nutrient release,

Table 17.13. Rates of N-P applied and chronology of fertilization program at Colstrip, Montana.

Treatment (Duration/Rate)	Application rate (kg/ha) of available N and P[a] on:					
	June 10, 1975		April 28, 1976		April 14, 1977	
	N	P	N	P	N	P
Fertilized 1st year only (F1)						
a) No fert. (A0)	NA	NA	NA	NA	NA	NA
b) Light rate (A1)	37	41	NA	NA	NA	NA
c) Medium rate (A2)	74	41	NA	NA	NA	NA
d) Heavy rate (A3)	121	41	NA	NA	NA	NA
Fertilized 1st & 2nd years (F2)						
a) No fert. (A0)	NA	NA	NA	NA	NA	NA
b) Light rate (A1)	37	41	37	11	NA	NA
c) Medium rate (A2)	74	41	74	11	NA	NA
d) Heavy rate (A3)	121	41	121	11	NA	NA
Fertilized 1st, 2nd & 3rd years (F3)						
a) No fert. (A0)	NA	NA	NA	NA	NA	NA
b) Light rate (A1)	37	41	37	11	37	11
c) Medium rate (A2)	74	41	74	11	74	11
d) Heavy rate (A3)	121	41	121	11	121	11

Source: Adapted from DePuit and Coenenberg (1979)

[a] Actual applied elemental P, converted from P_2O_5 (P_2O_5 rates were 94 kg/ha in 1975 and 25 kg/ha in 1976 and 1977.)

Table 17.14. Baseline (pre-treatment) reconstructed soil properties of study site at Colstrip, Montana in November 1974.

Soil Test[a]	Soil Depth (cm) 0-30	30-60	60-90	90-120
NO_3-N (ppm)	2.2	5.3	3.9	4.5
K (ppm)	54	57	56	57
Ca (meq/100g)	29	21	20	20
Mg (meq/100g)	2.2	2.2	2.3	2.1
Na (meq/100g)	0.1	0.1	0.1	0.1
Electrical Conductivity (mmhos/cm)	0.4	0.7	0.8	0.8
pH	8.8	8.4	8.2	8.2
Organic Matter (%)	0.15	0.15	0.15	0.15
Sand (%)	73	53	58	56
Silt (%)	14	31	26	28
Clay (%)	13	16	16	16
Textural Class	Sandy Loam	Sandy Loam	Sandy Loam	Sandy Loam

Source: DePuit and Coenenberg (1979).
[a]P data for 1974 are unavailable due to improper analysis procedures.

Table 17.15. Effects of fertilization rate on soil nitrogen and phosphorus after first year of fertilization program, fertilizer study, Colstrip, Montana, November, 1975. (0 to 30 cm soil depth)[a].

Fertilization Rate	NO_3-N(ppm)	NH_4-N(ppm)	P(ppm)
Not fertilized	2.2 a	8.4 a	11.0 a
Light rate (37 kg/ha)	3.1 ab	12.4 a	11.7 a
Medium rate (74 kg/ha)	2.5 a	4.5 a	13.0 a
Heavy rate (111 kg/ha)	4.5 b	15.6 a	14.6 a

Source: DePuit and Coenenberg (1979).
[a] Values in columns followed by same letter not significantly different at 5% level.

Table 17.16. Mean response of selected reconstructed soil properties to fertilization duration and rate, Colstrip, Montana, 1977 and 1978.

Soil Test	Soil Depth (cm)	Mean response to fertilization duration: Plots not fertilized 1977	1978	Plots fertilized in 1975 1977	1978	Plots fertilized in 1975 and 1976 1977	1978	Plots fertilized in 1975, 1976 and 1977 1977	1978	Mean response to fertilizer rate: Plots not fertilized 1977	1978	Plots fertilized at light rate 1977	1978	Plots fertilized at medium rate 1977	1978	Plots fertilized at heavy rate 1977	1978
NO_3-N (ppm)	0 to 5	NS[c]	T[b]	NS	T	NS	T	NS	T	NS	T	NS	T	NS	T	NS	T
	5 to 15	NS	T	NS	T	NS	T	NS	T	NS	T	NS	T	NS	T	2	T
	0 to 15	1	T	1	T	T	T	2	T	1	T	1	T	1	T	2	T
NH_4-N (ppm)	0 to 5	NS	2	NS	2	NS	3	NS	3	NS	2	NS	2	NS	3	NS	3
	5 to 15	NS	2	NS	2	NS	1	NS	1	NS	2	NS	2	NS	1	NS	1
	0 to 15	5	2	5	2	4	2	5	2	5	2	6	2	4	2	3	2
Total N (%)	0 to 5	NS	0.047	NS	0.048	NS	0.053	NS	0.050	NS	0.047	NS	0.050	NS	0.049	NS	0.051
	5 to 15	NS	0.041	NS	0.034	NS	0.037	NS	0.036	NS	0.041	NS	0.038	NS	0.034	NS	0.035
	0 to 15	NS	0.043	NS	0.039	NS	0.042	NS	0.041	NS	0.043	NS	0.042	NS	0.039	NS	0.040
P (ppm)[a]	0 to 5	NS	2	NS	5	NS	8	NS	7	NS	2	NS	2	NS	2	NS	2
	5 to 15	NS	2	NS	2	NS	2	NS	2	NS	2	NS	2	NS	4	4	4
	0 to 15	3	2	4	3	5	4	5	4	3	2	5	4	5	4	4	4
K (ppm)	0 to 5	NS	95	NS	91	NS	95	NS	98	NS	95	NS	91	NS	97	NS	95
	5 to 15	NS	64	NS	63	NS	69	NS	69	NS	64	NS	66	NS	70	NS	65
	0 to 15	65	74	78	72	77	78	67	79	65	74	73	74	72	79	76	75
Organic matter (%)	0 to 5	NS	0.700	NS	0.689	NS	0.733	NS	0.755	NS	0.700	NS	0.689	NS	0.689	NS	0.800
	5 to 15	NS	0.478	NS	0.467	NS	0.489	NS	0.478	NS	0.478	NS	0.555	NS	0.455	NS	0.422
	0 to 15	0.6	0.552	0.6	0.541	0.6	0.570	0.6	0.570	0.6	0.552	0.6	0.600	0.5	0.533	0.6	0.548
C:N Ratio	0 to 5	NS	14.9	NS	14.4	NS	13.8	NS	15.1	NS	14.9	NS	13.8	NS	14.1	NS	15.7
	5 to 15	NS	11.7	NS	13.7	NS	13.2	NS	13.3	NS	11.7	NS	14.6	NS	13.4	NS	12.1
	0 to 15	NS	12.8	NS	13.9	NS	13.6	NS	13.9	NS	12.8	NS	14.3	NS	13.7	NS	13.7

Source: DePuit and Commonberg (1979)

[a] Olson Method

[b] T = trace (<1 ppm)

[c] NS = not sampled

particularly of nitrogen, is influenced by granule size, solubility, acidity, temperature, moisture, and soil microbiology. Different compounds are affected differently by external factors acting individually or in concert.

Requirements may be predictable from spoil characteristics (a model is available that may be applicable in the oil sands). However, methodology used for analysis of natural soils may not be appropriate for spoil analysis. Therefore, predictions based on such analyses, particularly in the long-term, must be viewed with caution.

Amendments such as topsoil, irrigation, and mulch may be more important than fertilizer or may enhance fertilizer effects.

Suggested areas for further research include: (1) long-term fertility needs (particularly in climatic areas similar to Alberta); (2) soil-plant nutrient cycling; (3) species nutrient requirements; and (4) fertilizer alternatives.

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18. COAL ASH AS AN AMENDMENT

In coal fired power plants fly ash and bottom ash are wastes of considerable quantity. Total ash production in Alberta is believed to be in the order of 1.5 to 2 x 10^6 t/a, approximately 75% of which is fly ash (Joshi 1981). Part of the fly ash is used as an additive or binder in concrete with the remainder and all bottom ash stored in lagoons or mine pits. Ash has been used experimentally as an amendment in spoil reclamation. Ash is also being tried experimentally as an amendment in reconstructed soils over spoils and as an amendment on natural sodic soils. Research has also been directed at the problems of reclaiming the waste ash dumps and lagoons. Emphasis in this review is focused on the use of ash as an amendment in reconstructed soil over spoils.

18.1 ASH CHARACTERIZATION

Pluth, Gwyer and Robertson (1981) discussed the analytical problems associated with characterizing fly ash. The high content of spherical particles, especially cenospheres (hollow spheres) and plerospheres (spheres within spheres) markedly influences the measurement of particle distribution, cation exchange capacity, pH, buffer reactions used to determine spoil neutralization or lime requirement, and any measurement dependant upon aqueous ash extraction techniques. Thus measurements based on aqueous ash extraction techniques are difficult to interpret because extractable concentrations were particularly dependent upon dilution and extraction pH. The authors suggested extractions for fertility analysis should be done at a standardized pH representing the prevailing pH in a given fly ash spoil or soil mixture ("ambient pH").

For example, it was suggested that EC measured by typical extraction overestimates salinity status in fly ash compared to soils. To compensate for this dilution and pH effect in assessing the capacity of fly ash to neutralize acid spoils and soils, the authors used four extraction and neutralization techniques. The estimated neutralizing capacities for the ash samples were dependent upon the method used

(Table 18.1), and upon the final pH of the ash-spoil mixture (Figure 18.1).

Several authors have reported on the chemical and mineralogical properties of Alberta fly and bottom ash. The mineralogical properties are shown in Table 18.2. Measurements from similar coal deposits in the U.S. Great Plains and Great Britain are also included in the same Table. The Alberta fly ashes are very similar in mineralogical composition while those from the U.S. Great Plains exhibit more variation. In the Alberta fly ashes, the largest component is SiO_2 followed by Al_2O_3 and CaO. There is sufficient CaO for the ash to have some limited liming potential. The information on the other chemical and physical properties and extracts of Alberta fly ashes is summarized in Table 18.3. In contrast to their mineralogical properties, there are marked differences between ash from different sources (Tables 18.1 and 18.3; Figure 18.1). Some properties varied markedly (e.g., CaO content, neutralizing capacity, Na, Ca, K, and particularly heavy metals such as Cr, Cu, and Mn). Other properties such as texture and alkalinity were relatively similar in different ashes. Differing rates of mineralization increased this variability when compared to total levels. Salt extraction produced the most variable results. McCoy et al. (1981) reported on the temporal variation of mineralogical components of two Alberta ashes (Table 18.4).

There is also an apparent lack of reproducibility of analytical results as authors often reported markedly different values for ash from the same sources.

Fly ash characterization for the U.S. Appalachian and English coalfields is also reported in Tables 18.2 and 18.3, since this will facilitate evaluation of the research on fertility aspects of ash amendment which has been done in these other geographical locations. Capp (1978) summarized several publications (Schumen and Taylor 1978; Capp, Gillmore and Simpson 1975; Capp and Gilmore 1973, 1974; Adams,

Table 18.1. pH and neutralizing capacities of fly ashes in Alberta.

Source	pH			Neutralizing capacity (meq H^+/g fly ash)			
				Methods[a]			
	Sat'n paste	1:2 H_2O	1:1 $CaCl_2$	A[b]	B	C	D[c]
Grande Cache	9.6	8.8	8.8	1.3	0.20	2.3	0.4
Wabamun	12.4	11.8	11.8	4.6	0.51	5.7	1.4
Sundance	12.8	12.6	12.6	4.6	0.74	5.0	1.5
Forestburg	12.5	11.5	11.5	5.2	0.44	5.2	1.2
Sheerness	12.2	11.4	11.4	3.9	0.17	4.1	0.4

Source: Pluth, Gwyer and Robertson (1981)

[a] Pure $CaCO_3$ would have a value of 20 meq H^+ /g

[b] Estimated from Figure 5.50 at pH 6.0.

[c] Extraction methods:

A Fly ash heated to boiling in a 0.5 N HCl solution and then the amount of HCl neutralized was determined.

B Fly ash equilibrated with distilled water overnight, then heated on a steam bath for one hour followed by titration of the mixture with 0.2N HCl to pH 6.5. Heating on the steam bath and titrating with HCl was repeated four times. Neutralizing capacity is reported as the total amount of H^+ consumed per gram of fly ash during four titrations.

C Calculation of neutralization capacity from elemental composition of fly ash as follows:

$$NC = (Ca, K, Mg, Na) - SO_4$$

Where NC is neutralization capacity in meq H^+ neutralized per gram fly ash

Ca, K, Mg, Na, SO_4 are meq of total cations and meq of extractable SO_4-S.

D Soil + fly ash mixtures of between 0 to 30%. Fly ash were equilibrated in H_2O at a 1:2 soil-ash/H_2O ratio for three days, after which pH's of the solutions were measured. Lime requirements of the soil used (Boundary soil series, Ap horizon) was determined simultaneously by adding $Ca(OH)_2$ to the soil at various rates and equilibrating as with the soil-fly ash mixtures. The resultant pH vs. meq H^+ neutralized relationship was used to estimate the meq H^+ neutralized by fly ash for all rates and sources. The H^+ neutralized per gram of fly ash was plotted against equilibrium pH.

Table 18.2. Mineralogical composition of fly ash in Alberta, Great Britain, and the Northern Great Plains of the United States.

Mineralogical Series	Alberta			Great Britain	Wyoming		Montana	Kansas			Lignite
	Wabamun	Sundance	Forestburg (Battle River)		Medicine Bow County	Campbell County	Colstrip County	Lacygne County	Montrose County	Kemmerer County	
SiO_2 [a]	50.6	48.9	49.1	40 to 60	36.4	34.0	39.0	32.3	46.4	54.7	32.6
Al_2O_3	22.4	23.9	23.5	20 to 40	25.3	13.0	21.5	18.7	16.5	16.9	10.7
Fe_2O_3	4.5	3.40	5.0	6 to 16	6.0	3.4	3.70	5.06	19.7	7.21	18.0
CaO	16.8	15.3	17.0	2 to 10	3.8	20.0	25.2	31.3	9.06	8.11	7.31
MgO	1.72	0.49	0.53	1 to 4	1.2	6.0	4.73	4.00	0.48	2.36	2.60
SO_3	0.28	0.29	0.27	0.5 to 2	1.7	13.7	0.67	2.75	1.23	0.93	0.87
Na_2O	0.65	2.94	3.16	2 to 6	0.7	2.8	0.60	1.97	0.61	1.38	0.68
K_2O	0.97	0.69	1.06		2.3	0.8	0.35	0.39	1.58	1.27	0.11
TiO_2	<1.0	<1.0	<1.0	ND	1.0	<1.0	<1.0	<1.0	<1.0	<1.0	0.56
Free $Ca(OH)_2$	8.8	8.1	9.7	ND	ND	ND	20.0	17.0	5.3	4.4	ND

Source: Adapted from Joshi (1981)

[a] All measurements are in weight percent.

Table 18.3. Chemical characteristics of some fly and bottom ash from Alberta, Great Britain and the United States.

Characteristic[b]	Units[c]	Alberta							West Virginia	Great Britain	Ranges from the literature	
		Fly Ash					Bottom Ash		Fly Ash	Fly Ash	Fly Ash	Mineral soil
		Grande Cache	Edmonton	Sundance	Forestburg Battle River	Wabamun	Sundance	Forestburg Battle River				
Organic matter	% by weight		0.49	0.57	0.43							
B	µg/g		<100				100			350		
P	µg/g	622	200	180	1 590	600	170		1 000 to 2 000	1 160	600 to 8 000	50 to 2 000
K	µg/g	5 570	6 900	1 010	867	13 000	690		17 000 to 32 000	26 000	1 500 to 30 000	400 to 3 000
S	µg/g			1 200			300		1 500 to 4 000	4 000		
Texture	% sand/silt/clay	28/60/12	34/62/14	27/55/18	24/57/19	34/58/8		68/20/12		54/45/1		
CEC	meq/100 g	4.6	2.4	2.6	2.5	1.1		13				
SAR				3.2	23		1.2	1.3				
Saturation	%			43	38		70	68				
Bulk Density	g/cm³				1.2			1.0		0.99 to 1.23		
Saturated conductivity	cm/hr				9.2			200		24.8 to 0.13		
Moisture content (at field capacity)	% by volume			40.0			10.4					
Moisture content (at wilting point)	% by volume			5.0			0.5					
$CaCO_3$ equivalent	ppm			184 000			31 000					
Total:												
Ca	ppm	12 100	80 000	73 100	54 600	49 000	49 600		8 000 to 41 000		1 100 to 222 000	7 000 to 500 000
Mg	ppm	3 960	11 000	3,750	5 850	9 200	3 000		1 000 to 8 000		600 to 35 000	600 to 6 000
Na	ppm	1 450	23 000	8 680	8 530	11 000	3 500		1 000 to 6 000		100 to 35 300	600 to 20 000
Fe	ppm	15 000	32 000	15 600	19 300	42 000	14 600		51 000 to 160 000		10 000 to 250 000	7 000 to 550 000
Al	ppm	33 000	119 000	63 300	38 600	91 000	42 500		103 000 to 197 000		1 000 to 173 000	40 000 to 300 000
Sr	ppm	130		663	1 060		530					
Ba	ppm	500	4 000	1 440	800	4 000	1 200				110 to 10 000	100 to 3 000
Cu	ppm	38	90	23	14	30	10		60 to 200	248	33 to 1 000	
Zn	ppm	70		32	44		12		80 to 200	203		
Mn	ppm	130	950	264	215	1 500	330		0 to 300	842	125 to 1 000	
Pb	ppm	65		35	34		33		20 to 3 100	42		
Ni	ppm	31		45	32		19					
Cr	ppm	64	70	32	38	66	32				10 to 600	
Mo	ppm	28		16	20		22					
Cd	ppm	1.2		1.5	1.7		1.7					
Co	ppm	15		16	14		2.0					
V	ppm	112		66	67		30					
B	ppm								50 to 4 500	235		

Continued

Table 18.3. Concluded.

Characteristic[b]	Units[a]	Alberta							West Virginia	Great Britain	Ranges from the literature	
		Fly Ash					Bottom Ash					
		Grande Cache	Wabamun	Sundance	Forestburg Bottle River	Sheerness	Sundance	Forestburg Bottle River	Fly Ash	Fly Ash	Fly Ash	Mineral soil
Water extractable:												
EC	mmhos	1.9	4.7	9.1	2.0	1.6	0.6	0.8				
		11.5		12.4	11.6		8.7					
				1.5			0.5					
				1.0			1.0					
				<0.25			<0.25					1 1 800
		355.2		336.0	0.0			0.0		130 to 540		2 200
		326.4		96.0	1 651.2			1 632.0				
		473.2		1 451.6	625.6			561.4				
		4.6		4.6	39.1		41.4	57.5		2 800 to 18 700		8 000
		6.6		0.0	0.78			3.9				
		0.67		1.36	2.01					80 to 1 150		270
		34.83		29.16	280.88					10 to 2 250		1 300
		5.58		17.52	19.27					144		
		0.27		21.14	8.24							
		1.7		0.04	0.04							
		0.04		0.06	0.03					0 to 4		2.5
		9.07		9.07	239.04			61				
					60.26			42.54		3 to 150		
												2.5
Salt extractable:												
EC	mmhos	2.7	3.9	7.5	5.5	2.5						
Ca	ppm	3 200	1 100	13 000	5 100	1 800		2 548				
Mg	ppm	520	260	150	230	1 000		48				
	ppm	80	20	70	350	50		176				
	ppm	250	20	20	110	120		11				
	ppm	13	20	50	130	18						
S	ppm	1 400	150	250	440	270						
B	ppm	5	18	7	90	40				700 to 5 500		

Source: Compiled from Lutwick et al. (1981); McCoy et al. (1981); Pluth, Gwyer and Robertson (1981); Shaneman and Logan (1978); Capp (1978); Townsend and Hodgson (1973).

[a] Conversions = measurements were converted to common units. Some assumptions regarding valence of elements and compounds were necessary.

[b] Analytical techniques may vary. Refer to original papers.

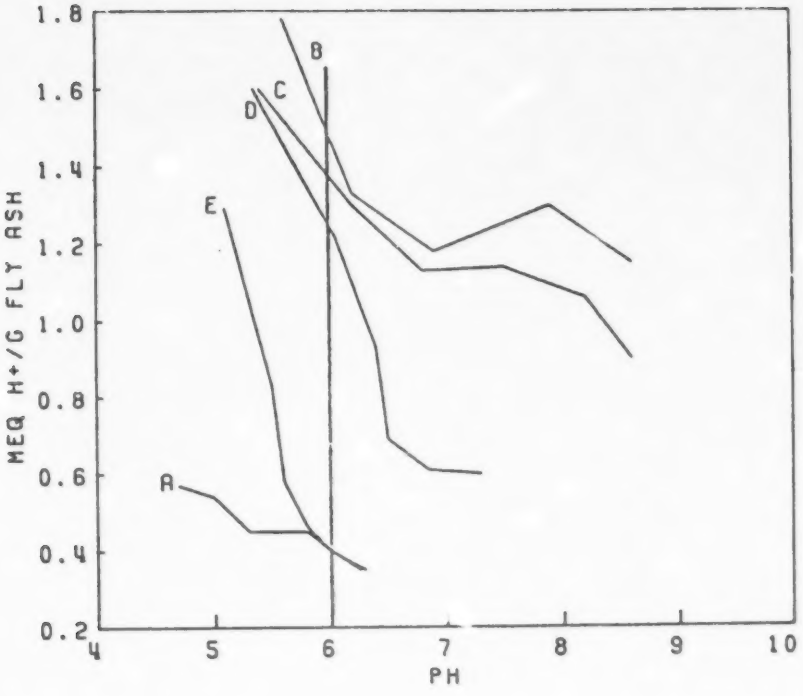

Figure 18.1. The relationship between equilibrium pH and neutralizing capacity of fly ash from Grande Cache (A), Sundance (B), Wabamum (C), Forestburg (D) and Sheerness (E).

Source: Pluth, Gwyer and Robertson (1981)

Table 18.4. Comparison of variances between monthly and more frequent samples -- deionized water extracts (E.C. to Li) and other procedures on two sources of ash in Alberta.

Parameter	F - Ratio[a]			
	Grande Cache		Battle River	
	Fly Ash	Bottom Ash	Fly Ash	Bottom Ash
E.C.	4.18	18.06[b]	1.76	1.46
Eh	2.30	0.057	1.70	5.57[b]
pH	17.78[b]	5.79	15.53[b]	8.53[b]
Ca	2.82	22.33[b]	46.11[b]	2.92
Mg	ND[c]	3.23	ND	2.54
Na	ND	1.29[b]	1.20	1.81
K	5.18	254.83[b]	2.47	1.81
OH	7.76[b]	ND	2.27	ND
CO_3	70.11[b]	6.60[b]	4.86[b]	ND
HCO_3	ND	27.32[b]	ND	1.52
SO_4	5.31	5.97	1.62	1.63
B	9.83[b]	26.32[b]	3.68	16.36[b]
F	65.01[b]	0.671	6.68[b]	ND
Fe	2.27	69.26[b]	2.75	12.35[b]
Zn	0.001	ND	ND	2.41
Ba	ND	ND	1.04	ND
Al	3.69	ND	7.13[b]	ND
Sr	1.84	5.40	1.27	6.18[b]
Li	5.39	3.86	ND	ND
TKN	0.369	2.28	1.42	2.75
TC	0.370	2.58	1.42	0.145
TS	7.24[b]	3.29	0.166	3.36
NO_3-N	4.57	26.00[b]	2.03	1.01
NH_4-N	16.55[b]	0.049	1.10	10.47[b]
P	5.66	2.54	ND	1.24

Source: Adapted from McCoy et al. (1981)

[a] F-Ratio = monthly samples mean square/frequent samples mean square, i.e., denominator is an estimate of the variation within a month and is used as the error mean square.

[b] Monthly samples more variable than frequent samples ($\alpha = 0.005$).

[c] Not evaluated = too many observations were less than detection limits.

Capp and Gillmore 1972; Adams, Capp, and Eisentrout 1971; Capp and Adams 1971) and the analysis of seven ashes from West Virginia are reported here. Townsend and Hodgson (1973) presented a detailed characterization of English fuel ash including texture, chemical composition, macro- and micro-nutrients, and bulk density (Table 18.3).

18.2 ASH UTILIZATION

Ash has been used as an amendment in soil reconstruction to: (1) raise the soil pH or neutralize spoil acidity; (2) add some nutrients or enhance spoil fertility; (3) improve spoil structure; (4) improve spoil moisture characteristics; and (5) create a barrier to moisture flux and diffusion between toxic spoil and non-toxic reconstructed soils.

Ash utilization also entails certain risks or problems including: (1) direct toxicity (e.g., metals); (2) indirect or induced toxicities or deficiencies (e.g., Fe and Al precipitation of P); (3) leaching of metals and groundwater contamination; and (4) deterioration of soil structure when Na rich ash is used.

18.2.1 Liming Potential

The best documented effect of ash amendment is that of neutralization or pH elevation. Pluth, Gwyer and Roberton (1981) assessed the neutralization or liming feasibility of Alberta fly and bottom ash. All the fly ashes were extremely alkaline (Table 18.1) yet despite this, ash neutralizing capacities tended to be very low and varied markedly, partly due to problems of measuring specific properties reliably, and partly due to variations in CaO content. Based then on CaO and total Ca contents, fly ash from Forestburg, Sundance, Wabamun, and Battle River should have some limited liming potential (Joshi 1981; Tables 18.2 and 18.3).

Considerably more work on liming potential of ash has been done in the U.S. and in Europe. Capp (1978) working in West Virginia, reported on experiments in 12 sites between 1966 and 1974 where fly ash with a pH of 11 to 12 was added to the spoil. The spoils ranged from pH 2.5 to 4.7 before amendment. After amending with 336 to 1792 t/ha of ash, spoil pH rose to between pH 5.1 and 7.4. In Kansas, the effect of fly ash on spoil pH and plant growth was studied in vitro. These studies utilized three spoils, two of which were strongly acidic, and one which was slightly acidic (Murphy 1971). The fly ash treatment ranged from 0 to 1794 t/ha. On the strongly acidic soils, pH was increased from 4.2 to 7.2 at one site, and from 3.0 to 5.0 on the second site by the 1794 t/ha of fly ash. The same results were achieved using 8.5 to 2.8 t/ha of lime.

Liming potential is an agronomic concept which can sometimes be extrapolated to non-agricultural situations. Mathematical models were developed to estimate the quantity of chemical amendment needed to raise the pH of acid soils to desired levels. These lime requirement models are discussed in detail in Chapters 11.4.1 and 46.2.4. Knabe (1973), however, reported little success with the agronomic models for estimating lime requirement in acid spoils and developed his own technique and model for ash amendment of soil to estimate ash liming potential.

Knabe (1973) described a reclamation process used in West Germany, termed the Domsdorft treatment. One of the key components of this system is brown coal ash amendment. The process includes liming with brown coal ash, fertilization, and cultivation (ploughing) to 30 and 60 cm soil depth. Experience has indicated that traditional lime requirement determinations were unreliable for the acid toxic West German spoils. The traditional agricultural techniques or models for estimating lime requirement suggested very high liming rates (with agricultural lime) that proved to be ineffective. Conversely, treatment with coal ash reduced water repellancy of the spoil and achieved better acid neutralization (Table 18.5). The technique for assessing lime

Table 18.5. Effects of soil amelioration on acidity of toxic spoil; examples of medium and extreme toxic spoil before and eight months after treatment, in West Germany.

Treatment and depth of sample	pH (KCl)	Free acid meq/100 g	Loss on ignition %	Exchange capacity T-value meq/100 g
Medium toxic spoil				
Before amelioration:				
0-10-15	3.4	2.0	13	30
20	ND	ND	ND	ND
30	ND	ND	ND	ND
50	2.8	3.8	13	31
100	ND	ND	ND	ND
After 200 dt/ha CaO:				
0-10-15	4.9	0.8	11	ND
20	3.0	6.2	16	ND
30	2.7	11.0	14	ND
50	2.6	10.8	16	ND
100	3.1	2.4	4	ND
After 500 m^3/ha ash:				
0-10-15	6.9	0.3	21	51
20	3.3	2.8	13	49
30	3.1	3.3	10	29
50	2.9	3.7	12	54
100	3.0	3.8	20	44
Extremely toxic spoil				
Before amelioration:				
0-10-15	3.0	21.1	13	30
20	ND	ND	ND	ND
30	ND	ND	ND	ND
50	2.8	11.7	11	36
100	ND	ND	ND	ND
After 200 dt/ha CaO:				
0-10-15	3.9	2.8	17	ND
20	2.7	11.0	12	ND
30	2.7	10.3	10	ND
50	2.6	13.1	12	ND
100	2.6	8.1	14	ND
After 500 m^3/ha ash:				
0-10-15	5.4	0.4	20	21
20	3.2	10.6	7	28
30	3.1	19.4	9	31
50	3.1	23.1	10	20
100	3.2	25.0	11	23

Source: Knabe (1973a)

requirements for both lime and coal ash as described by Knabe (1973:289) is as follows:

> "Assessment of lime requirement according to the acid-base balance for both the surface layer and the subsoil.
>
> . Calculation: Inorganic S plus half the T-value [CEC] for reaching a pH 5.0, minus Ca and Mg soluble in 10% HCl gives the lime requirement (all in meq/100 g).
> . 1 meq/100 g equals 8.06 dt/ha CaO for a layer of 22.5 cm.
> . Requirements of both layers must be added when deep amelioration is undertaken.
>
> Assessment of required quantities of ash.
>
> . Areas with lime requirements below 150 dt/ha CaO should be limed; above 150 dt/ha CaO they should be treated with ash instead of lime.
> . The necessary quantity is calculated as follows:
>
> $$\frac{(10)\ (\text{lime requirement of spoil, dt/ha CaO})}{\%\ CaO + 1.4\ (\%\ MgO) - 0.7\ (\%\ SO_3)} = m^3/\text{ha of ash}$$
>
> where % CaO, MgO, and SO_3 are the percentages of these oxides in the ash, and the factors 1.4 and 0.7 are needed to convert MgO and SO_3, respectively, to equivalents of CaO."

Doyle (1976) also studied the use of fly ash as a liming amendment. The fly ash was slightly alkaline and K rich (Table 18.6). It was less effective overall than sewage effluent, sewage sludge or lime, but faster acting. In some of the soils tested, (presumably coarse textured and poorly buffered), ash raised pH by as much as three units, whereas in other soils (presumably fine textured and/or strongly buffered and/or with initial high pH levels), ash increased pH by less than one unit (Figure 18.2). Whereas most authors reported that fly ash treatment on acid spoils raised pH, Chadwick (1973) reported that 27 t/ha of lagooned pulverized fly ash did not significantly raise acid mine spoil pH in Yorkshire, England. In Alberta, Lutwick et al. (1981)

Table 18.6. Chemical and physical characteristics of soil and fly ash, from Appalachia.

Sample	Organic Matter (%)	pH	Effective available exchange			CEC (meq/100 g)	Bulk Density (g/cc)	Field Capacity (%)	Texture		
			$CaCO_3$ kg/ha	P kg/ha	K kg/ha				Sand (%)	Silt (%)	Clay (%)
Soil A	1.7	4.8	8408	56	288	12.7	1.18	20.6	28	72	0
Soil B	1.5	3.1	22420+	213	104	14.1	1.19	27.5	22	74	4
Soil C	2.2	6.3	3363	38	283	14.1	1.18	24.1	22	74	4
Fly ash	ND	7.7	ND	47	1121+	ND	1.48	17.0	46	52	2

Source: Adapted from Doyle (1976)

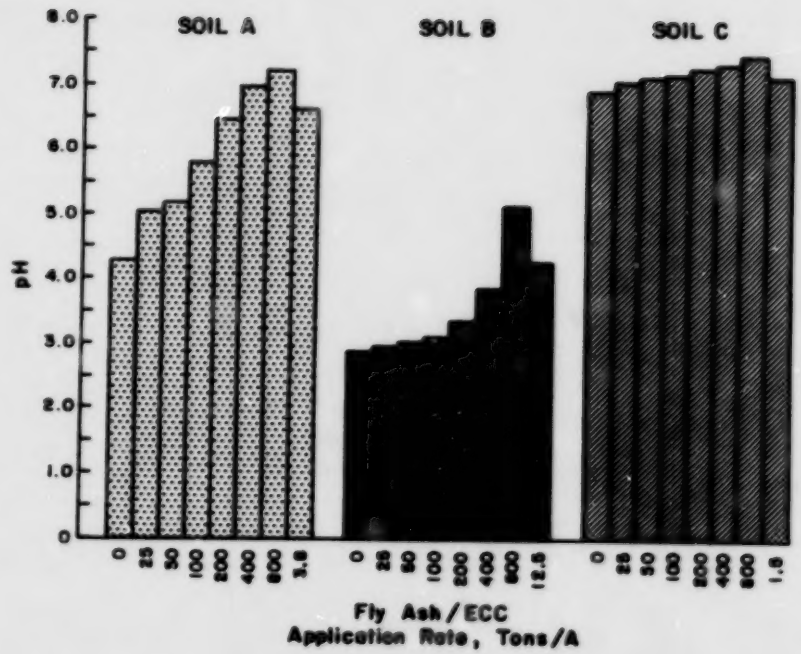

Figure 18.2. Effect of fly ash on pH of three Kansas soils incubated for 10 weeks.

Source: Doyle (1976)

reported on pH change with fly and bottom ash amendments to soil. Fly ash from Genesee increased ash-soil pH while fly ash and bottom ash from Forestburg and Bow City and bottom ash from Genesee caused no significant change in ash-soil pH.

18.2.2 Fertility and Toxicity Potential

18.2.2.1 Fertility. It would appear that Alberta fly and bottom ashes have minimal nutrient value. This has been shown, for example, by Shaneman and Logan (1978) who reported on experiments by Manalta Coal Ltd. using 4 to 15 cm surface application of bottom ash in place of sand and topsoil. Heavy fertilization was required for successful establishment of a dryland grass legume mixture of Medicago sativa, Melilotus sp., Panicum sp., and Hordeum vulgare. Such fertility limitations are explained by the ash-spoil chemistry.

McCoy et al. (1981) reported that N and P levels in ashes from Battle River, Alberta were too low to be considered a significant fertilization input (Table 18.3). Pluth, Gwyer and Robertson (1981) also reported that the value of these ashes as fertilizers was minimal. This was due to low total levels of N, K, and S, which in turn, yielded low levels of elements as soluble constituents (Table 18.3). Furthermore, despite the high level of total and extractable P in some ashes (Table 18.3), the relatively high levels of water soluble and reactive compounds containing Ca, Al, and Fe in the fly ash would tend to irreversibly fix P in precipitated forms which are unavailable to plant uptake in ash soil or spoil mixtures.

Plant materials grown on fly ash treated soils in West Virginia were lower in K, P, Ca, Mg, and N than plant materials grown on undisturbed soils (Capp 1978). In contrast, Wochok, Fail and Hosmer (1976) in in vitro studies on spoil from central Alabama showed yield increases in response to minimal amounts of fly ash amendment. It was assumed the yield increases were due to increased spoil fertility (Table 18.7). Townsend and Gillham (1975) and Townsend and Hodgson (1973) discussed fuel ash fertility effects in Great Britain. English

Table 18.7. Effect of fly ash amendment on soybean yield in Alabama spoils.

Fly Ash t/ha	Average Dry Weight (gms)	Average Height (cm)
0.0	1.70	13.25
10.3	1.89	16.00
20.4	2.32	19.25
30.7	3.13	19.40

Source: Adapted from Wochok, Fail and Hosmer (1976).

fuel ash is, on average, deficient in N with adequate P and rich in K (Table 18.3; Townsend and Hodgson 1973). In addition, P and K may be low in some ashes, while Ca, Mg, S, and micronutrient levels tend to be high (Townsend and Gillham 1975).

18.2.2.2 Toxicity. Some risk of toxicities from ash amendment are probable in Alberta as has been found elsewhere. Salinity is also a risk from ash amendment in Alberta. The most probable toxic elements are B, Mn, and Se. McCoy et al. (1981) reported that ash from Battle River, Alberta was sufficiently rich in B to cause B toxicity if used as an amendment. Lutwick et al. (1981) observed B toxicity symptoms on Hordeum vulgare and Medicago sativa grown on ash-soil and ash-spoil mixtures in vitro. Soils and spoil used included a Dark Brown Solodized Solonetz from near Forestburg and a Dark Grey Solodized Solonetz from near Genesee, Alberta, and mine spoil from near Bow City Alberta, fly ash and bottom ash were collected from Calgary Power's Sundance plant. Yield decreases attributed to B toxicity were from 10 to 34%. Similarly, in recent experiments, Palmer has detected B toxicity in vitro, however this was not reproduced in situ with ash-soil mixtures (Craig Palmer, Alberta Environment, personal communication). Natsukoshi (1981) has reported B toxicity in situ in response to ash amendment of spoil.

Using extractant measurements, Pluth, Gwyer and Robertson (1981) also speculated that plant Mg deficiency could be induced in ash amended soil for most Alberta fly ashes.

It has also been reported in Alberta (McAllister Environmental Services Ltd. 1978) that fly ash amendment of spoil at 67 t/ha substantially increased the Se content of hay, but not to the toxic level.

Generally, reports from outside Alberta confirm what is known or suspected about the possible toxicity of ash amendment. Plant materials grown on fly ash treated soils in West Virginia were higher in Fe, Cu, B, Mn, Al, and Se than plant materials grown on undisturbed soils (Capp 1978). Only B and Al levels were high enough to cause

toxicity. Agropyron intermedium, Lotus corniculatus, and Melilotus officinalis appeared more tolerant to fly ash than other forage species.

Table 18.8 summarizes some of the typical trace element constituents of fly ash, soil, and Hordeum vulgare on some reclaimed soils in Great Britain (Davies, Gilliham and Simpson 1971). Only B levels exceeded the toxic limit. Also in Britain, Townsend and Gilliham (1975) reported toxic levels of Cr, Ni, and Pb in fuel or fly ash. Townsend and Hodgson (1973) reported toxic levels of Zn and B in fly ash (Table 18.3).

In England, Townsend and Hodgson (1973) reported that weathering of ash in disposal piles or lagoons seemed to reduce its toxicity. Thus they argued that fuel ash was frequently unsuitable for reclamation without prolonged weathering or substantial artificial treatment (Townsend and Gilliham 1975). Davies, Gilliham and Simpson (1971) studied the use of ash amendment for the reclamation of gravel pits and other similar disturbed sites in Britain. They also found that old ash (although they did not specify how old) was less toxic than fresh ash and that soil ash mixtures were less toxic than ash alone.

No such long term data or experience exists for Alberta's ash. Recent laboratory leaching experiments suggest Alberta fly ashes would undergo a two stage leaching process (Dudas 1981). In the initial phase, there would be some rapid leaching of select highly soluble elements in salt form causing initial potential alkalinity and B and Al toxicities. This would be followed by a second phase of very slow release of virtually all elements with the risk of toxicities being very small. However, the ash contribution to the nutrient pool during this slow leaching would also be negligible (Table 18.9). Thus the danger of metal leachates contaminating groundwater would also be minimal.

18.2.3 Effects on Structure and Soil Moisture

The effects of ash amendment on spoil structure and moisture status are difficult to predict, particularly when ash and spoil characteristics and soil climate vary markedly. Positive effects have been reported. For example, Capp (1978) reported moisture retention in

Table 18.8. Trace elements in soil, fuel ash and barley grown on soil and ash in Great Britain.

Elements	'Available'[a] in:		Contained in DM of barley grown in:		Plant content required to show toxicity
	Soil ppm	Pulverized fuel ash ppm	Soil ppm	Pulverized fuel ash ppm	ppm in DM
Ag	1	1	--	--	--
Al	58	144	38	66	425
As	ND	ND	2	10	100
B	2.5	4.3	18	1200	600
Co	1.6	8.5	10	10	640
Cr	1.7	22	1	10	257
Cu	2.5	25	10	30	92
Fe	130	570	1000	1000	--
Mn	35	233	100	100	5400
Mo	0.2	5.4	5	100	1540
Ni	2.7	60	0.3	1	153
Pb	10	10	--	--	--
Se	2	ND	10	10	137
Sn	10	10	100	100	--
Ti	10	15	30	100	ND
V	1.3	6	3	10	ND
Zn	2.6	2.1	57	40	200

Source: Adapted from Davies, Gillham and Simpson (1971).

[a] Soluble in 2.6% acetic acid, except boron which is that soluble in boiling water.

Table 18.9. Chemical composition of a fresh and weathered fly ash, from Alberta, after leaching with 993 (column A), 1957 (column B), and 3367 (column C) pore volumes of distilled water.

Element	Fresh Ash	Column A		Column B		Column C	
		Top	Bottom	Top	Bottom	Top	Bottom
Composition in %							
Al	11.9	12.6	12.2	12.9	12.4	13.2	12.7
Ba	0.49	0.52	0.49	0.52	0.54	0.55	0.56
Ca	10.0	6.88	8.16	6.29	7.82	5.96	7.06
Fe	2.84	2.98	3.00	3.10	3.02	2.88	2.85
K	0.489	0.514	0.476	0.534	0.500	0.534	0.501
Mg	0.644	0.642	0.680	0.612	0.695	0.608	0.685
Na	2.48	2.58	2.48	2.70	2.56	2.68	2.58
Composition in ppm							
B	480	390	440	270	310	110	170
Cd	2.0	1.9	1.9	2.1	2.0	1.9	2.1
Co	14	13	14	14	12	12	14
Cr	37	27	29	28	30	26	27
Cu	45	48	44	51	45	55	47
Hg	0.22	0.17	0.26	0.30	0.27	0.24	0.23
Mn	480	480	490	530	530	500	520
Mo	52	44	45	45	46	43	45
P	890	910	940	810	1000	770	950
Pb	100	105	100	115	105	125	115
Sr	1100	860	930	790	920	770	860
V	100	92	100	84	100	80	94
Zn	86	93	92	97	95	98	93

Source: Dudas (1981)

sites in West Virginia was beneficially increased from 9.1% to 13.5% on spoil and from 12.7% to 18.5% on a refuse dump when both were amended with ash. Ash can also have beneficial effects on spoil structure as the creation of crumb structures and increased earthworm colonization have been reported (Satchell and Stone 1977).

In studying English fly ashes, Townsend and Hodgson (1973) reported some systematic patterns to ash variability. Despite relatively similar textures and similar chemical composition of the fly ashes, hardness, bulk density, and permeability varied widely (Table 18.3; Townsend and Hodgson 1973). Conversely, in mineral soils, if texture and chemical composition were relatively similar between different soils, one would expect their physical properties, such as bulk density and permeability, to be relatively similar.

Soils or spoils with high clay contents, especially of the expanding clay lattice types, are the most susceptible to dispersion by Na. Levels of soluble or exchangeable sodium which are unlikely to precipitate, will tend to disperse soil aggregates. This causes puddling or sealing during soil moisture infiltration, which in turn induces a very low saturation conductivity. Adding ash to soil or spoil could then conceivably cause a deterioration in soil structure if the ash contains more free sodium than the soil. This ash characteristic can be used to advantage when it is desirable to create a barrier to moisture flow between toxic and sodic (Na rich) spoil and overlying non-sodic topsoil.

If fly ash amendment to non-saline soil is limited to 15 to 30% ash, salinity problems should not be induced (Pluth, Gwyer and Robertson 1981). However, some ashes with high Na:Ca ratios would probably be more susceptible to cause such dispersion and the ensuing problems of inadequate stable aggregation. In experiments with ash soil mixtures using Alberta materials, Lutwick et al. (1981) found the predominant effect was no change. When chemical effects (including pH, SAR, and EC changes) and physical effects (including modulus of rupture and hydraulic conductivity) were detected, generally they were

favourable, enhancing spoil fertility and physical structure (Table 18.10).

18.3 SUMMARY

Aqueous ash extraction techniques are difficult due to the physical characteristics of the ash. Chemical characterization of ashes is therefore very dependent on the extraction method used.

Mineralogical properties of Alberta ashes are quite similar. However, chemical characteristics vary greatly between sources and temporally within sources. Reproducibility of analyses is also difficult.

Coal ash may be used to raise pH or neutralize acidity, enhance fertility, improve structure, improve moisture capacity, and to provide a barrier to vertical moisture flux.

Amendment with coal ash may also result in direct and indirect toxicities, groundwater contamination, and deterioration of soil structure.

Agronomic models for determining liming potential do not work well for coal ash. One method devised for calculating the liming potential of ash is included.

Alberta coal ash has minimal liming potential and minimal nutrient value. Boron toxicity in plants grown on ash or ash-soil mixtures has been reported in Alberta and Mn and Se toxicity is possible. Metal toxicities have been reported elsewhere. Weathered ash is reportedly less toxic than fresh ash; however, the initial weathering process may result in plant toxicity and groundwater contamination.

Coal ash may improve structure and moisture holding capacity. However, results have been variable and in fine textured spoils high Ca:Na ratios can cause soil dispersion. In tests carried out in Alberta to date physical effects have been favourable. Physical properties of ash vary widely despite similar textures and chemical characteristics, and therefore physical effects on spoils are also likely to vary.

Table 18.10. Changes in chemical and physical properties of plant samples and ash-soil mixtures from Alberta sources as a result of ash addition ($\alpha = 0.05$).

	Fly ash			Bottom ash		
	Forestburg	Genesee	Bow City	Forestburg	Genesee	Bow City
Ash-soil mixture						
pH	-[5]	↑	-	-	-	-
SAR[1]	-	↓	-	-	-	-
EC[2]	-	↑	-	-	-	-
B	↑	↑	↑	↑	-	↑
MR[3]	-	-	↓	-	-	↓
HC[4]	-	↑	-	-	↑	-
Barley						
Yield	↓	-	↓	-	↑	-
TKN	-/↑[6]	↑/↑	-/↑	-/-	-/-	-/-
Fe	-/↑	-/↑	-/↑	-/-	-/-	-/-
Zn	↑/↑	-/-	↑/↓	-/-	-/↓	-/-
Mn	↑/-	↑/↑	-/↑	-/↓	-/-	-/-
Cu	↑/-	-/-	-/-	-/-	-/-	-/-
P	-/-	-/↑	-/↓	-/-	-/-	-/-
Alfalfa						
Yield	↓	-	-	-	-	-
TKN	-	↑	na[7]	-	↑	na
Fe	-	-	-	-	-	-
Zn	-	-	-	-	-	-
Mn	-	↓	-	-	↓	-
Cu	↑	↓	↑	-	-	-
P	-	-	↑	-	-	-

Source: Lutwick et al. (1981)

1 Sodium adsorption ratio
2 Electrical conductivity
3 Modulus of rupture
4 Hydraulic conductivity
5 Representation of changes in relation to coal ash addition to soil
↑ indicates an increase in the measured parameter
- indicates no change in the measured parameter
↓ indicates a decrease in the measured parameter
6 Grain/straw
7 Not analyzed

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19. SEWAGE AND WASTE MATERIALS AS AMENDMENTS

19.1 REGULATIONS AND SOCIAL IMPLICATIONS

Land disposal of sewage and similar waste materials has been practiced in a purposeful way for centuries. In England in the early part of the 19th century, land disposal of sewage was practiced to combat cholera epidemics. This was in effect primary treatment. Using sewage to improve soil productivity evolved from this early necessity for sewage treatment. The need for safe sewage disposal still exists in urban societies. In rural societies sewage materials are useful for improving soil productivity. Thus, there is sustained interest in sewage effluent and sludge applications to farms, parks, golf courses, and other anthropogenic soils.

Land disposal of sewage and sewage plant products may be particularly important in rehabilitation of drastically disturbed lands. Sewage is often rich in the nutrients that are often deficient in drastically disturbed lands, particularly strip mine spoils. Sewage, however, may also be undesirably enriched with heavy metals and harmful bacteria or other pathogens. Offensive odours may create public resistance to land disposal of sewage or sewage plant products. Thus, the careful control and regulation of processing and disposal of sewage wastes is needed. Current regulations are not specific to drastically disturbed lands such as strip mined areas.

Government policy in Alberta sets the following criteria for primary sewage treatment, required before pond storage and land application:

Parameter	% Removal	Effluent Value
BOD (5d at 20°C)	24 to 45	100 to 150 mg/L
Coliform Bacteria	40 to 60	25×10^6/100 mL
Suspended Solids	35 to 65	100 to 150 mg/L

Further guidelines include land application rates, application season, crops grown, and precautions preventing uncontrolled disposal.

In Alberta, little, if any, sewage waste is applied to strip mined land. Considerable research has been done in the eastern U.S., especially in Pennsylvania and Illinois. In these states, large strip mined areas are located close to large urban centres.

19.2 PROPERTIES OF SEWAGE MATERIALS

The reaction of sewage and sewage treatment products with soils, spoils, and vegetation has been extensively researched. Hortenstine and Rothwell (1972) described the composition of a compost produced microbiologically from residential and commercial solid wastes. It contained 50% moisture, 5500 ppm N, 2000 ppm K, 20 400 ppm Ca, 1200 ppm Mg, 47 ppm B, 215 ppm Mn, and 672 ppm Zn. These values are 10 to 50 times greater than for similar contents reported in liquid sludge. Sludges from the Pennsylvania State University Sewage treatment plant (Sopper, Kardos and Edgerton 1974) were studied by Dickerson (1971) and are described in Table 19.1.

The major plant nutrients and the metals contents of various sewage sludges sources (Tables 19.2 and 19.3; Halderson and Zenz 1978) indicate the magnitude and variability of sludge constituents in the United States and Britain. Such sludge characteristics for 32 cities, towns, and villages in Alberta are shown in Table 19.4 (D.A. McCoy, Alberta Department of Environment, personal comm.). Evidently, the major plant nutrient content of the Alberta sludges is similar to those in the United States. Heavy metals content of the Alberta sludges, however, is only a small fraction of that in sludges from the United States or Great Britain.

Milne and Graveland (1972) reported on sewage sludge in Alberta containing 7.5 meq/L Na, 59 meq/L Ca + Mg, 2.5 meq/L K, 777 ppm NO_3-N, 357 ppm available P, 1.2% total N, 0.83% total P, with a pH of 6.6, EC of 7.7 mhos/cm, and an SAR of 1.4.

Sewage effluent is compared with a standard municipal water supply in Table 19.5. Based on this comparison, sewage plant effluent

Table 19.1. Composition of two liquid digested sludges studied as mine spoil amendments in Pennsylvania.

Constituent	mg/L[a]	
pH	-	7.6
Organic N	195	932
P	118	125
K	136	80
Ca	82	136
Mg	27	34
Mn	2	1
Fe	18	15
Cu	2	1
B	1	0.4
Al	19	58
Zn	4	2
Na	48	34

Source: Adapted from Sopper, Kardos and Edgerton (1974) and Dickerson (1971).

[a] except pH.

Table 19.2. Major plant nutrients present in sewage sludge sources from the United States and Great Britain.

Constituent	% Dry Weight						
	Chicago WSWI[a]			Illinois--24 Cities		Seven States in U.S.[b]	
	Range		Median	Range	Mean	Range	Mean
Total N	4.2	to 9.6	6.8	2.6 to 9.8	5.4	0.03 to 17.6	3.2
NH_3-N	1.5	to 5.0	3.1	0.1 to 6.1	1.8	0.0005 to 6.7	0.7
P	1.1	to 8.1	2.8	0.7 to 4.9	2.4	0.04 to 6.1	1.8
S	0.35	to 1.3	0.98	ND	ND	ND	ND
K	0.2	to 0.8	0.4	ND	ND	0.008 to 1.9	0.3
Ca	0.3	to 4.8	2.1	ND	ND	0.1 to 25	5.1
Mg	0.6	to 1.7	1.1	ND	ND	0.03 to 2.0	0.5
Na	0.2	to 0.7	0.25	ND	ND	0.009 to.7	0.4

Source: Reproduced from Halderson and Zenz (1978), Reclamation of Drastically Disturbed Lands, 1978, pages 355-377 by permission of the American Society of Agronomy, Crop Science Society of America, and Soil Society of America.

a West-Southwest sewage treatment plant.

b Data from Agric. Exp. Stn. Committee on Utilization and Disposal of Municipal, Industrial, and Agricultural Processing Wastes on Land and represent select cities in seven states.

Table 19.3. Metals content of various sewage sludge sources from the United States and Great Britain.

Metal	ug/g dry weight basis									
	Chicago WSW[a]			Seven states in U.S.[b]			Great Britain[c]			
	Range		Median	Range		Mean	Range			Median
Ag	ND		ND	ND		ND	5	to	150	20
As	ND		ND	6	to 230	53	ND			ND
B	ND		ND	4	to 757	114	15	to	1 000	50
Ba	ND		ND	21	to 8 980	618	150	to	4 000	1 500
Bo	ND		ND	ND		ND	1	to	30	3
Bl	ND		ND	ND		ND	12	to	100	25
Cd	120	to 312	197	ND		ND	60	to	1 500	--
Co	ND		ND	1	to 18	5.3	2	to	260	12
Cr	11	to 4 120	2 400	17	to 99 000	3 290	40	to	8 800	250
Cu	680	to 2 270	1 380	84	to 10 400	1 260	200	to	8 000	800
Fe	15 400	to 49 000	36 300	400	to 90 000	12 000	6 000	to	62 000	21 000
Ga	ND		ND	ND		ND	1	to	20	8
Hg	0.8	to 7.5	3.2	ND		ND	--			--
La	ND		ND	ND		ND	30	to	150	60
Li	ND		ND	ND		ND	10	to	150	40
Mn	120	to 550	370	18	to 7 100	400	150	to	2 500	400
Mo	ND		ND	5	to 39	27	2	to	30	5
Ni	186	to 840	355	10	to 3 515	426	20	to	5 300	80
Pb	303	to 1 160	680	13	to 19 700	1 670	120	to	3 000	700
Sc	ND		ND	ND		ND	2	to	15	5
Sn	ND		ND	ND		ND	40	to	700	120
Sr	ND		ND	ND		ND	80	to	2 000	300
Ti	ND		ND	ND		ND	1 000	to	4 500	2 000
V	ND		ND	ND		ND	20	to	400	60
Y	ND		ND	ND		ND	15	to	100	40
Zn	1 670	to 4 850	2 770	13	to 27 800	2 900	700	to	49 000	3 000
Zr	ND		ND	ND		ND	30	to	3 000	150

Source: Halderson and Zenz (1978), as per Table 19.2.

[a] West-Southwest sewage treatment plant.

[b] Unpublished data from Agric. Exp. Stn. Committee on Utilization and Disposal of Municipal, Industrial, and Agricultural Processing Wastes on Land.

[c] Berrow and Weber (1972).

Table 19.4. Some chemical constituents of sewage sludges from Alberta.

		Maximum	Minimum	Median
Total N	%	10.7	1.75	3.82
NH_4 N	%	5.69	0.03	1.05
P	%	2.32	0.25	1.32
K	%	1.09	0.17	0.40
Ca	%	6.59	1.28	3.12
Mg	%	1.68	0.37	0.73
Na	%	3.37	0.03	0.16
Fe	%	2.05	0.18	1.26
Mn	ppm	963	81	180
Zn	ppm	1400	311	583
Cu	ppm	1300	160	538
Pb	ppm	1680	51	138
Ni	ppm	103	15	37
Cr	ppm	1700	22	110
Cd	ppm	15	4	6
Hg	ppm	6	1	2

Source: (D.A. McCoy, Alberta Environment, Earth Sciences Division personal communication).

Table 19.5. Composition of sewage plant effluent and municipal water supply in Pennsylvania.

Constituent	Composition mg/L				
	Effluent		Municipal Supply		
pH	7.3	7.2	7.4	7.3	6.4
organic-N	1.7	34.4	1.9	12.7	ND
NO_3-N	13.1	6.1	7.8	9.0	1.2
orthophosphate P	5.5	5.2	4.0	4.9	0.04
P	ND	5.6	ND	5.6	ND
K	23.6	13.7	6.2	14.5	3.5
Ca	34.2	34.9	15.9	28.3	7.7
Mg	17.9	16.0	2.7	12.2	1.4
Mn	0.1	0	0.3	0.13	0.11
Fe	0.9	0.5	2.3	1.23	1.7
Cu	0.2	0.2	0.7	0.37	ND
B	0.2	0.4	ND	0.3	ND
Al	0.7	0.9	ND	0.8	0.3
Zn	0.4	0.1	0.8	0.43	0.1
Na	38.2	35.2	ND	36.7	3.0

Source: Adapted from Dickerson (1971) and Sopper, Kardos and Edgerton (1974, 1976).

is higher in NO_3-N, Ca, K, orthophosphate P, Mg, and Na than the municipal supply. Sewage effluent, however, can vary markedly. For example, Pennsylvania effluent organic N varied from 1.7 to 34.4 mg/L among three reports (Sopper, Kardos and Edgerton 1974, 1976; Dickerson 1971).

19.3 ECONOMICS AND APPLICATION TECHNIQUES

Seitz (1974) used a deterministic simulation model to predict the economics of land reclamation with sewage sludge. Aerobically digested sludges from Chicago were used on strip mined land near Chicago. The parameters included: (1) transportation by barging and pipeline, (2) site preparation, (3) application of inorganic nitrogen, (4) various soil nitrogen balances, and (5) cropping systems. Results indicated that almost 136 dry t of sludge could be applied in the first 10 years with another 91 plus t in the following 10 years. At current costs, the project appeared economically feasible.

Halderson and Zenz (1978) discussed the practical aspects of sludge utilization for land reclamation, presenting all phases of the operation. Site preparation depends upon the initial conditions and the final proposed utilization. Agriculture requires minimal slopes, preferably <5%, although to avoid ponding, the land should not be flat. Sludge incorporation or injection may be sufficient; however, berms and run-off collection basins provide more permanent surface water contamination control. Groundwater protection measures also include initial surveys of soil and groundwater hydrology, application volumes to the crop and soil system, and groundwater monitoring. Frequently in excess of one half of sludge utilization costs are transportation costs. Liquid sludge may also require on-site storage basins and handling equipment such as pumps and pipelines. Application equipment may include grated pipe on areas of constant slope, sprinklers, or injection and incorporation equipment. Application rate is limited by soil organic matter content as soils with low organic matter react too slowly or in a too limited manner spatially to process the sludge. Most

sludges do not contain proper proportions of plant nutrients, and commercial fertilizers are necessary to correct nutrient imbalances.

Various authors have discussed the techniques of sludge application. Lynam, Sosewitz and Hinesly (1972) reported that the Metropolitan Sanitary District of Greater Chicago experimented with various spray irrigation systems. Sprinklers with nozzles less than 1.9 cm in diameter failed but a travelling irrigation system with 4.44 cm nozzle successfully applied sludge containing 10% solids at a rate of approximately 4.3 L/min. Dallaire (1974) also applied sludge with a large sprayer, covering a radius of up to 90 m.

19.4 EFFECTS ON SOILS

19.4.1 Soil Chemistry

Sewage effluent and sludge contains many essential elements for plant growth, although not necessarily in ideal proportions. Halderson and Zenz (1978) discussed the practical aspects of sludge utilization for land reclamation in Illinois. They indicated that most sludges do not contain the proper balance of plant nutrients. Commercial fertilizers are required to provide a nutrient balance. Horstenstine and Rothwell (1972) applied composted sewage sludge to phosphorus mine tailings and found that soil K, Ca, and Mg were increased significantly. Sopper, Kardos and Edgerton (1974) in Pennsylvania, found that sewage plant effluent and sludge applied to strip mine spoil increased the content of K, Ca, Mg, and Na while Mn, Fe, A, and Zn were unchanged in concentration. Considerable N was added and retained by the spoil.

Spoil pH may be increased by ion exchange through effluent and sludge irrigation. Scanlon, Duggan and Bean (1973) found a tendency for reduced acidity where heavy rates of municipal compost was applied to coal strip mine sites for two years. They indicated compost at 58 to 159 t/ha was required to stabilize an organic layer on mine spoils in two or three years.

Sewage sludge or effluent has only recently been studied as an ameliorant on strip mine spoils in Alberta, though nothing has been published to date. However, Graveland (1973) working with Lethbridge Loam, an Orthic Dark Brown Chernozem, found that sludge increased the C:N ratio considerably beyond the optimum, pH and soluble salts increased, and the SAR remained constant.

McMillan and Carlson (1975) summarized the results of pilot scale and full scale projects to assess the suitability of applying waste sludges from the Metropolitan Sanitary District of Greater Chicago to landfill and acid strip mine spoils. They found that soil pH was increased. On an alkaline silica sand waste pit, plant nutrient concentration and organic matter were increased. Raising the pH prevented metal ions from going into solution.

In vitro experiments by Graveland and Terakita (1973) investigated the use of air-dried activated sludge on subsoil to create a favourable growth media for lawns and parks. The pH, EC, and SAR decreased slightly as sludge rate was increased. Where no crop was grown, available phosphorus increased from 0 to 30% of the soil-sludge mixture. Where beans were grown, available phosphorus increased from 2 to 12% with increased sludge application. The increased available P was due to rapid mineralization of organic P in the sludge. Where plants were grown, plant uptake absorbed much of the P released, thus causing the measured levels of available P to be lower.

Milne and Graveland (1972) studied the effect of adding digested sludge to three Orthic Brown Chernozemic soils. Their properties are described in Table 19.6. Nitrate produced by nitrification increased up to 101 t/ha on maximum sludge amendment in all soils, with the Coaldale soil showing the greatest increase (Figure 19.1).

Loebel, Lowe and Beauchamp (1978) found increases in available NO_3, NH_4, P, and exchangeable K as well as an increase in EC on coarse soils amended with sewage. They noted that sewage was a more effective amendment than dairy manure or sawdust.

Table 19.6. Chemical composition of three soils and sewage sludge in Alberta.

Soil	pH	EC mmhos/cm	Cations		K	SAR	Nutrients Available		Total %	
			Na	Ca + Mg meq/L			NO_3	P	N	P
Cavendish SL	7.1	0.5	0.9	4.5	0.5	0.6	2.0	10.0	0.23	0.05
Coaldale CL	7.7	2.6	15.4	13.9	0.6	5.9	30.6	27.4	0.16	0.07
Lethbridge L	7.7	2.8	3.1	26.0	3.1	0.9	38.6	10.5	0.21	0.06
Sludge	6.6	7.7	7.5	56.0	2.5	1.4	777.	357.	1.20	0.83

Source: Milne and Graveland (1972).

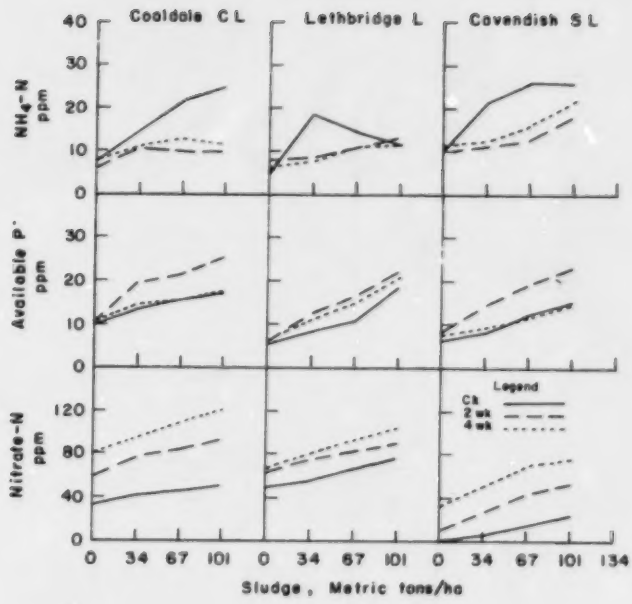

Figure 19.1 NO_3-N, NH_4-N, and available P in soils before and after incubation for two and four weeks with three levels of sludge, from the Lethbridge, Alberta area.

Source: Milne and Graveland (1972)

Chicago area spoil contains ≥30% clay, primarily illite, and therefore has a high ammonium-fixing capacity. Approximately 70% of the N in lagooned sludges is mineralized at about the same rate as soil organic N. About 30% is readily available NH_4-N; however, about half of the soluble N is volatized. Hinesley, Jones and Sosewitz (1972) concluded that 448 t/ha of dry lagooned sludge may be incorporated into the surface 30 cm of cultivated strip mined soils during a four-year period.

Mathias, Bennet and Lundberg (1979) studied application of lime, sewage sludge, and shredded garbage on strip mine spoil near Fort Martin, West Virginia. The effects were not always systematic or linear. Generally, pH, P, and cation levels, including Ca, Mg, and K, increased with marked increases at the high sludge application rate of 22 t/ha (Table 19.7).

In experiments in northeastern Minnesota, Brooks, Borovsky and Mace (1979) experimented with application of secondary sewage effluent on sandy loam textured iron ore spoil. The effluent loading rates are described in Table 19.8. At the first site, effluent irrigation changed total soil nutrient levels little, leaching some Cl_2 down the profile. At the second site, effluent irrigation lowered extractable P (Bray), NO_3 + NO_2, NH_4, and Na at depth, while increasing total N, P, and Na in the surface horizons (Table 19.9, Figure 19.2). Total N increased by less than 1%, whereas P increased by 75% near the spoil surface. Increases in total Na of up to 50% by 10 cm/wk effluent irrigation could eventually cause structural problems. Overall N removal varied from 80 to 98% and with P removal at around 99% of the total added in the effluent.

Kerr, Sopper and Edgerton (1979) studied amendment of burned anthracite spoil with a combination of treated sewage effluent and domestic sewage. The spoil was moderately acidic pH = 5.0, and rather infertile. Plant survival and growth, spoil fertility amelioration, and leachate quality were studied. The effluent loading rates are summarized in Tables 19.10 and 19.11.

Table 19.7. Effect of lime, sewage sludge, and shredded garbage on pH, and P, K, Ca, and Mg concentrations of strip mine spoil in West Virginia.

Treatment (t/ha)					Nutrient Concentration(kg/ha)			
Lime	Sewage Sludge	Garbage	Date	pH	P	K	Ca	Mg
0	0	0	11/73	3.5	11	95	414	166
			11/76	3.8	48	243	448	59
0	112	0	11/73	5.3	71	96	5 846	302
			11/76	5.6	122	214	6 916	202
0	224	0	11/73	6.3	42	100	10 013	302
			11/76	6.5	125	171	12 404	569
11.2	0	0	11/73	6.6	19	81	8 758	240
			11/76	6.1	77	211	6 076	97
11.2	112	0	11/73	6.9	33	94	11 692	297
			11/76	6.4	99	210	11 340	185
11.2	224	0	11/73	6.9	37	80	11 581	383
			11/76	6.8	70	143	12 544	218
0	0	22.4	11/73	4.0	24	110	974	138
			11/76	4.1	57	281	728	55
11.2	0	22.4	11/73	6.6	17	107	9 677	198
			11/76	6.5	78	230	8 344	97

Source: Mathias, Bennett and Lundberg (1979). Reproduced by permission of Penn State Press.

Table 19.8. Average concentrations and cumulative additions of nutrients from applied effluent on Site I (1975) and Site II (1976), in northeastern Minnesota.

Nutrient	Mean Concentrations (mg/L)			Cumulative Additions (kg/ha)				
				Site I (1975)			Site II (1976)	
	Typical Secondary Effluent[a]	Site I	Site II	Maximum (6.1 cm)	Medium (3.8 cm)	Minimum (3.7 cm)	Maximum (120 cm)	Minimum (60 cm)
$(NO_3 + NO_2)$-N	NA	0.56	0.23	0.3	0.2	0.2	2.8	1.4
Total Kjeldahl N	20.00	10.20	15.40	6.1	3.8	3.8	184.8	92.4
NH_4-N	NA	NA	6.93	NA	NA	NA	NA	NA
Total P	10.00	2.20	3.58	1.3	0.8	0.8	43.0	21.5
Calcium	24.00	35.60	25.20	21.5	13.4	13.3	302.4	151.2
Magnesium	17.00	16.60	10.20	10.0	6.3	6.2	122.4	61.2
Sodium	50.00	45.60	50.30	27.5	17.2	17.0	603.6	301.8
Potassium	14.00	7.60	7.06	4.6	2.9	2.8	84.7	42.4
Chloride	45.00	68.20	57.20	41.3	25.7	25.4	686.4	343.2
Boron	1.00	NA	0.78	NA	NA	NA	9.3	4.7
SAR[b]	2.70	NA	2.14	NA	NA	NA	NA	NA
Total Solids	425.00	NA	458.50	NA	NA	NA	5502.0	2751.0

Source: Brooks, Borovsky and Hace (1979). Reprinted by permission of Penn State Press.

[a] Pound and Crites (1973).

[b] Sodium adsorption ratio.

Table 19.9. Effluent quality and renovation efficiencies at 1.0- and 1.2-m depths for Sites I and II respectively, in northeastern Minnesota.

	$(NO_3 + NO_2)$-N	Total Kjeldahl N	NH_4	Total P	Ca	Mg	Na	K	Cl
Site I									
Effluent concentration (mg/L)	0.56	10.2	ND	2.2	35.6	16.6	45.5	7.6	68.2
Renovation efficiency[a] (%) at 1.2 m									
Minimum	32	89	ND	95	-127	-265	86	61	78
Medium	-43	90	ND	99	-160	-377	87	55	36
Maximum	98	89	ND	99	-177	-431	78	51	22
Site II									
Effluent concentration (mg/L)	0.28	15.4	6.93	3.58	25.2	10.2	50.3	7.06	51.2
Renovation efficiency[a] (%) at 1.0 m									
5 cm/wk	-6.203	88	98	99+	-540	-602	24	-265	-26
10 cm/wk	-7.063	86	99	99+	-580	-614	10	-281	-31
Site II									
Renovation efficiency[b] (%) at 1.0 m									
5 cm/wk	-10.476	90.5	ND	99.5	-394	-445	45.4	-161	26
10 cm/wk	- 6.402	80	ND	99.5	-430	-455	32.3	-209	21

Source: Brooks, Borovsky and Mace (1979). Reprinted by permission of Penn State Press.

[a] Renovation efficiency = 1 - [percolate concentration (mg/L)/effluent concentration (mg/L)] x 100.

[b] Renovation efficiency = 1 - [quantity of constituent in soil percolate (kg/ha)/quantity in effluent (kg/ha)] x 100.

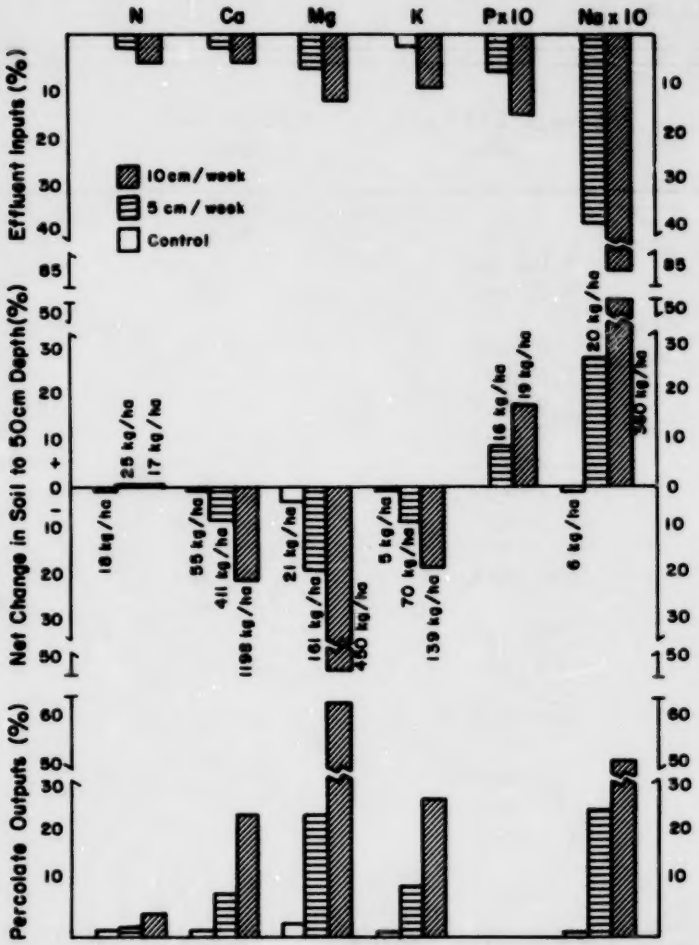

Figure 19.2. Nutrient balance estimate as a percentage of initial soil capital at the 50 cm soil depth. Site II.

Source: Brooks, Borovsky and Mace (Jr.) (1979)
Reproduced by permission of Penn State Press.

Table 19.10. Chemical analysis of the bi-weekly sewage effluent and city water samples and the heat-dried sludge from Pennsylvania source.

Mean	Sewage Effluent Mean	City Water Mean	Sludge Mean[a]
pH	7.4	6.35	8.7
Ortho P	4.01 mg/L	0.04 mg/L	
Total P	4.20 mg/L		0.55%
Total N			2.16%
NO_3-N	7.8 mg/L	1.2 mg/L	301 ug/g
NH_4-N	3.3 mg/L		50 ug/g
Org. N	1.9 mg/L		21 240 ug/g
K	6.2 mg/L	3.5 mg/L	253 ug/g
Ca	15.9 mg/L	7.7 mg/L	4215 ug/g
Mg	2.7 mg/L	1.4 mg/L	3431 ug/g
Na	32.6 mg/L	3.0 mg/L	548 ug/g
Cl	48.1 mg/L		
Fe	1643 ug/L	1700 ug/L	2251 ug/g
Al		300 ug/L	2500 ug/g
Mn	269 ug/L	110 ug/L	300 ug/g
Cu	81 ug/L	30 ug/L	732 ug/g
Ni			38 ug/g
Zn	263 ug/L	100 ug/L	797 ug/g
Co			22 ug/g
Cr	22 ug/L		207 ug/g
Pb	81 ug/L		686 ug/g
Cd	2.7 ug/L		1.3 ug/g
Dry solids			96%
Vol. solids			61%

Source: Kerr, Sopper and Edgerton (1979). Reprinted by permission of Penn State Press.

[a] Five separate samples of sludge were analysed. All values are expressed on a dry-weight basis.

Table 19.11. Total amounts of the macronutrients nitrogen, phosphorus, and potassium supplied to the refuse in the effluent, city water, and sludge applications, Pennsylvania source.

Treatment	Amounts of Nutrients Applied (kg/ha)		
	N	P	K
Effluent (34.7 cm)a	45.3	14.6	21.4
Water (36.2 cm)[a]	8.5	0.1	12.7
Sludge (40 t/ha)	804.0	221.7	10.1
Sludge (75 t/ha)	1507.5	415.7	19.0
Sludge (150 t/ha)	3015.0	831.4	38.0

Source: Kerr, Sopper and Edgerton (1979). Reprinted by permission of Penn State Press.

[a] Total amounts of effluent and water (in area-centimeters) applied to the respective plots during the 1974 growing season.

They also studied in detail the N cycling and balance. For example during the initial growing season nitrogen uptake by Phalaris arundinacea increased with increasing sludge application (Table 19.12). After the second and third growing seasons, N content of grass decreased in sludge amended plots partly due to increasing competition for nutrients.

From the widely varying estimates in the literature (Table 19.13) the authors assumed an N mineralization of 40% in the initial year followed by 10% in subsequent years. Using these figures, however, grossly underestimates N mineralized within three years. If one assumes all crop residues are mineralized in one year then the plant N uptake varies between 61 and 97% of available N in the sludge amended plots.

In Illinois, near Chicago, Peterson, Pietz and Lue-Hing (1979) studied the effects of amending spoils with sludge. Their study is particularly useful since they compared sludge amended spoil with sludge amended unmined agricultural soils. Comparing spoils and agricultural soils similar to the original soil suggested the original soil was more fertile and less toxic than the spoil (Table 19.14). For example the spoil had very high bulk density (1.61 g/cm^3) and higher heavy metal levels than the soil. Further, the spoil had about 1% less organic carbon and lower CEC and nitrate levels. Amending spoil with sludge did not cause consistent changes in spoil pH which varied from 6.8 to 8.0 (Table 19.15). Conversely, amending natural cropped soils with sludge caused marked acidification as pH dropped from around 6.5 to around 5.6. Following this initial pH drop the soil pH remained constant (Table 19.15). The authors suggested that this acidification was due to increased nitrification and production of organic acids. Thus, there was some indication of increased nitrate levels in groundwater (Table 19.16). These sludge amended natural agricultural soils then would require liming to restore their pH balance.

Over time sludge amendment did tend to increase organic carbon in cropped and fallow spoil and available P in fallow spoil. Amendment

Table 19.12. Nitrogen uptake by Phalaris arundinacea (no irrigation plot) on sludge amended spoils in Pennsylvania.

Year	Sludge Rate (t/ha)	DMP (kg/ha)	Foliar Nitrogen (%)	Nitrogen Uptake (kg/ha)	Nitrogen Applied (kg/ha)	Nitrogen Available (sludge)[a] (kg/ha)	Nitrogen Available (crop residue)[a] (kg/ha)	Total Nitrogen Available (kg/ha)	Vegetation Uptake of Available Nitrogen (%)
1974	0	305	1.78	5	0	0	0	0	ND
	40	2 225	3.08	69	804	322	0	322	21.4
	75	3 046	4.13	126	1 508	603	0	603	20.9
	150	793	4.43	35	3 015	1 206	0	1 206	2.9
1975	0	1 701	1.78	30	0	0	2	2	ND
	40	6 519	1.54	100	0	48	27	75	133.3
	75	6 408	2.01	129	0	91	49	140	92.1
	150	6 157	2.54	156	0	181	13	194	80.4
1976	0	1 610	1.78	29	0	0	14	14	ND
	40	6 887	2.02	139	0	43	56	99	140.4
	75	10 563	1.92	203	0	81	58	139	146.0
	150	12 731	2.48	316	0	163	76	239	132.2

Source: Kerr, Sopper and Edgerton (1979). Reprinted by permission of Penn State Press.

[a] Assume 40% mineralized first year, 10% of remaining in subsequent years.

Table 19.13. Sludge mineralization rates:percent organic N mineralization.

First Year	Second Year	Third Year	Fourth Year	Reference
40	--	--	--	a
33		(Reduced rate)		b
30	5 to 6	5 to 6	5 to 6	c
25	25	25	25	d
20	20	20	20	e
15 to 20	3	3	3	f
15 to 20	3	3	3	g
15	6	4	2	h
15	6	4	2	i
10	5	5	5	J

Source: Kerr, Sopper and Edgerton (1979). Reprinted by permission of Penn State Press.

a Interim guidelines for sewage, septic tank, and holding tank waste on agricultural lands. 1977. The rules and regulations of the Department of Environmental Resources, Commonwealth of Pennsylvania, Chapter 75, Subchapter C, Section 75.32.

b B.D. Knezek and R.H. Miller (eds.), 1976. Application of sludges and wastewaters on agricultural land: A planning and educational guide. Section 6, analysis and their interpretation by B.G. Ellis. Research Bulletin 1090, Ohio Agricultural Research and Development Center, Wooster, Ohio. pp. 6-1 to 6-6.

c Ohio guide for land application of sewage sludge. 1976. Research Bulletin 1079. Ohio Agricultural Research and Development Centre, Wooster, Ohio.

d Utilization of sewage sludge on agricultural land. 1975. Agronomy facts. College of Agriculture, University of Illinois, Urbana, Ill.

e Illinois Advisory Committee on sludge and Wastewater utilization on agricultural land. 1975. Illinois Environmental Protection Agency, Springfield, Ill.

f B.D. Knezek and R.H. Miller (eds.), 1976. Application of sludge and wastewater on agricultural land: A planning and educational guide. Section 3. Analysis and Their Interpretation by L.E. Sommers and D.W. Nelson. Reseach Bulletin 1090, Ohio Agricultural Research and Development Center, Wooster, Ohio, pp. 3-1 to 3-7.

g U.S. Environmental Protection Agency. 1977. Municipal sludge management: Environmental factors. EPA-430/9-77-004.

h Council for Agricultural Science and Technology, U.S. Environmental Protection Agency. 1976. Application of sewage sludge to cropland. EPA-430/9-76-013.

i Guidelines for the application of wastewater sludge to agricultural land in Wisconsin. 1975. Technical Bulletin 88. Department of Natural Resources, Madison, Wis.

J Land Application of Wastes. An educational program: nitrogen considerations (Module #15). 1976. Environmental Studies Program, Cornell University, Ithaca, N.Y.

Table 19.14. Soil characteristics of nonmined and strip-mined lands near Chicago, Illinois, prior to the application of sewage sludge

Soil Characteristics[a]	Nonmined Areas	Strip-Mined Areas
pH	6.5	7.4
Organic carbon (%)	1.64	0.61
EC (mmhos/cm)	0.68	1.29
CEC (meq/100 g)	19.5	14.3
NH_4-N (µg/g)	5.79	6.59
(NO_2 + NO_3)-N (µg/g)	2.85	1.77
0.1 *N* HCl extractable		
Zn (µg/g)	31.4	31.7
Cd (µg/g)	0.08	0.20
Cu (µg/g)	2.62	4.79
Ni (µg/g)	7.5	6.7
Texture	Loam, silty loam	Loam, silty clay loam, clay loam
Classification	Typic hapludalf, aeric ochraqualf	
Bulk density (g/cm^3)	1.29	1.61

Source: Peterson, Pietz and Lue-Hing (1979)

[a] Most of the data were taken from Peterson and Papp-Vary (1972) and Zenz et al. (1976).

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Table 19.15. Digested sewage sludge application rate and soil pH for typical mined and nonmined fields at Fulton County land reclamation site, Illinois.

Field Number	Agricultural Use	Sludge Applied (dry basis)[a] (t/ha) 1972	1973	1974	1975	Soil pH[b] 1973	1974	1975	1976
Mine spoil									
3	Cropped	12.9	2.7	54.7	22.8	7.8	8.0	6.8	7.2
4	Fallow	--	1.1	54.9	85.8	--	8.0	6.9	7.3
Nonmined									
20	Cropped	--	0.8	52.4	20.4	6.2	6.4	5.7	5.6
36	Fallow	--	--	--	84.9	--	6.8	6.6	6.6

Source: Peterson, Pietz and Lue-Hing (1979). Reprinted by permission of Penn State Press.

[a] Sewage sludge was applied to all fields by spraying in 1972 to 1973, to fields 3 and 20 in 1974, and to fields 3 and 36 in 1975. Sludge was applied by incorporation to field 4 in 1974 and fields 4 and 20 in 1975.

[b] Composite soil samples from 0- to 15-cm depth were taken each spring prior to sludge application. Soil pH was determined using a 1:1 soil/water ratio.

Table 19.16. Watershed management characteristics for two reservoirs on the MSDGC site in Fulton County, Illinois.

Reservoir:	R3					R4			
Watershed area (ha):	1610					729			
Year:	1972	1973	1974	1975	1976	1973	1974	1975	1976
Sludge applied (mt)	585	289	980	12,520	19,790	38	12,852	15,694	5,155
Cropable area (ha)	159	236	276	276	276	46	153	186	186
Spray application (% of cropable)	100	100	100	17	39	100	30	50	0
Fallow (% of cropable)	0	0	26	66	57	0	89	39	34

Source: Peterson, Pietz and Lue-Hing (1979). Reprinted by permission of Penn State Press.

of natural soils markedly increased available P but had little systematic effect on organic carbon (Table 19.17).

Sewage and waste materials often contain relatively large concentrations of heavy metals. This may present a hazard where effluents and sludges are applied to lands that produce crops particularly for direct human consumption. John and Van Laerhoven (1976) in pot experiments using soil from the Lower Fraser Valley, British Columbia, studied the potential hazards of heavy metal contamination in food crops from sludge application to the soil. Cadmium concentrations increased significantly when sludge or Milorganite (pelletized processed sewage sludge pellets produced in Millwaukee, Wisconsin) was added in amounts greater than 5 g/kg of soil. Greater concentrations of Cd were found in the soil when the soil was limed, presumably because plant uptake was supressed. Some increases were shown for concentrations of Cu, Ni, and Mn (Table 19.18). Pb and Fe were considerably increased by the application of sludge or Milorganite.

Hinesley, Jones and Sosewitz (1972) reviewed the use of sludge for strip mine reclamation, particularly anaerobically digested sludges from Chicago. They stated that spoils can absorb and overcome the trace element problems possible from soil sludge application, particularly if the spoil is fine textured.

Halderson and Zenz (1978) suggested that heavy metal accumulation is not a significant hazard when application amounts do not exceed plant nitrogen requirements. Soil pH should be kept above 6.5. Sludge applications should be limited to 55 dry t/ha if crops are to be grown in the same year. A fallow year may be advisable if the application rates are higher.

Greenhouse and laboratory studies of the effect of sludge on extractable metals in sludge-treated soil were reported by Gaynor and Halstead (1975; Tables 19.19 and 19.20). Sludge increased C, pH, cation exchange capacity, exchangeable Ca, and extractable P and increased the levels of extractable An, Cu, Pb, and Cd. Less metals were extractable

Table 19.17. Available phosphorus and organic carbon content for typical sludge-amended mine spoil and unmined field at Fulton County, Illinois, land reclamation site[a].

Field Number	Agricultural Use	Available P (ug/g dry soil) 1974	1975	1976	Organic Carbon (% of dry soil) 1974	1975	1976
Mine spoil							
3	Cropped	20	12	34	0.86	0.96	1.22
4	Fallow	8	14	46	0.62	1.32	1.25
Unmined							
20	Cropped	42	59	83	2.25	2.46	2.03
36	Fallow	12	8	75	0.84	0.54	1.12

Source: Peterson, Pietz and Lue-Hing (1979). Reprinted by permission of Penn State Press.

[a] Composite soil samples from 0- to 15-cm depth were taken each spring prior to sludge application. Available phosphorus was determined by extraction with 0.03 N NH_4F + 0.025 N HCl (Olsen and Dean 1965), and organic carbon was determined by Walkley-Black method (Allison 1965). [see original paper for full references].

Table 19.18. Concentrations of heavy metals in British Columbia soils treated at 25 g/kg dried sludge or milorganite and limed or not limed.

Metals (ppm) and pH	Control		Sludge		Milorganite	
	Unlimed	Limed	Unlimed	Limed	Unlimed	Limed
Pb	6.8	5.5	21.2	21.6	24.2	25.3
Cu	26.2	28.5	30.5	33.5	33.6	38.1
Ni	5.6	5.1	6.3	5.6	6.9	7.4
Mn	184	211	200	262	249	219
Fe	2278	3075	3247	3380	4410	4360
pH	5.6	6.4	5.7[a]	6.4[a]	5.1[a]	5.8[a]

Source: Adapted from John and Van Laerhoven (1976), Journal of Environmental Quality, Volume 5, 1976, pages 246-251 by permission of the American Society of Agronomy, Crop Science Society of America, Soil Science Society of America.

[a] Average of four reps.

Table 19.19. Chemical properties of untreated and sludge-amended soils after eight weeks incubation.

Soil treatment	pH[b]	Total C %	Total N %	Available Nutrients[a] P ppm	Available Nutrients[a] N ppm	Exchangeable Cations meq/100 g CEC	Ca	Mg	K
Granby sandy loam									
Untreated	6.6	12.7	0.66	37	40	24.5	44	5.0	0.52
Sludge added	7.0	13.0	0.65	51	17	28.1	49	5.4	0.55
Rideau clay									
Untreated	5.6	2.4	0.20	46	28	18.7	14	3.4	0.64
Sludge added	6.8	3.1	0.26	53	15	21.1	24	3.4	0.66
Fox sandy loam									
Untreated	6.7	0.6	0.05	43	17	5.8	5	0.7	0.16
Sludge added	7.3	1.3	0.12	52	4	6.2	12	0.9	0.22

Source: Adapted from Gaynor and Halstead (1975).

[a] $NaHCO_4$ NO_3 extractable.

[b] 1:2 ratio in distilled water.

Table 19.20. Extractable metal concentration and conductivities of untreated and sludge-amended soils.

Soil treatment	Conductivity (mmhos/cm)	0.005 M DTPA-extractable metals (ppm)			
		Zn	Cu	Pb	Cd
Granby sandy loam					
Untreated		7.7	4.4	3.4	0.37
Sludge		52.8	11.5	6.2	0.70
Sludge + fertilizer, incubated[a]	3.37	58.4	9.1	6.1	0.94
Sludge + fertilizer, cropped[b]	1.60	62.6	17.8	7.8	0.97
Rideau clay					
Untreated		5.7	2.2	1.8	0.14
Sludge		74.6	2.8	5.5	0.72
Sludge + fertilizer, incubated[a]	3.66	25.9	8.8	3.9	0.52
Sludge + fertilizer, cropped[b]	1.40	20.7	7.8	3.8	0.45
Fox sandy loam					
Untreated		1.0	0.7	1.6	0.07
Sludge		31.1	4.9	3.5	0.25
Sludge + fertilizer, incubated[a]	2.91	35.1	9.6	5.0	0.46
Sludge + fertilizer, cropped[b]	1.84	20.7	6.6	2.9	0.32

Source: Gaynor and Halstead (1975).

[a] Incubated at field capacity 11 months in greenhouse.

[b] Cropped three times to lettuce.

from the Fox sandy loam than from the Rideau clay soil. Metals added to the Granby sandy loam were not strongly chelated by organic matter. Because of the coarser texture and lack of mineral exchange sites, the metals were more readily available for chemical extraction. Thus, sludge application to coarse textured soils may result in an increased metal uptake by some crops. It is essential to know the metal content of the sludge, the frequency and amount of application, and the type of soil and crop to be grown.

Hill, Hinkle and Klingensmith (1979) provide an interesting summary of the natural processes by which heavy metals are removed from the aqueous and gaseous flux systems (Table 19.21). He could have added that the strength of the four retention processes decreases as follows: PR < AD < CE < AE.

Four heavy metals studied showed marked systematic increases in concentration in the soil in response to sludge amendment (Peterson, Pietz and Lue-Hing 1979). Both spoil and soil in fallow and crops showed similar Zn, Cd, Ni and Cu increases over time with sludge amendment (e.g., Tables 19.22 and 19.23).

Metal uptake by plants on sludge amended burned anthracite spoil was detected for Zn, and Cd in Phalaris arundinacea and Ni in Vicia cracca (Kerr, Sopper and Edgerton 1979). As soil pH increased over time, metal uptake decreased (e.g., Table 19.24).

Spoil N and P levels, including extractable P increased near the spoil surface enhancing spoil fertility (Figure 19.3). Of the heavy metals, Cu, Zn, and Cd did accumulate near the spoil surface in heavily amended spoil plots; however, only Cd levels exceeded those normal for natural local soil (Table 19.25).

19.4.2 Soil Physics and Groundwater

Several authors reported physical improvements of strip mine spoils after application of sewage and similar waste materials. Els (1978) for example, suggested septic tank sludge as an amendment for coarse-textured incinerated urban waste.

Table 19.21. Removal mechanism of heavy metals in soil.

Element	Removal Mechanism[a]	Element	Removal Mechanism
Aluminum	PR, S	Lead	AD, CE, S
Arsenic	AD, S	Lithium	CE, W
Beryllium	PR	Manganese	PR, CE, S
Boron	AD, W	Mercury	AD, CE, S
Cadmium	AD, CE, S	Molybdenun	AD, S
Chromium	AD, CE, S	Nickel	AD, CE, S
Cobalt	AD, CE, S	Selenium	AE, W
Copper	AD, CE, S	Silver	AD, CE, S
Fluoride	AD, S	Zinc	AD, CE, S
Iron	PR, CE, S		

Source: Compiled by Hill, Hinkle and Klingensmith (1979). Reproduced by permission of Penn State Press.

[a] AD, Adsorption with iron or aluminum hydroxide, pH-dependent; AE, anion exchange; CE, cation exchange; PR, precipitation, pH-dependent--iron and manganese are also subject to changes by oxidation reduction reaction; S, strong strength of removal; W, weak strength of removal.

Table 19.22. Zinc concentrations (ug Zn/g dry basis) of surface soils and crops for typical sludge-amended mine spoil and nonmined fields at Fulton County, Illinois land reclamation site.

Land Type	Field Number	Agricultural Use	Year 1972	1973	1974	1975	1976
					Soil[a]		
Mine spoil	3	Cropped	20.0	--	20.9	71.6	133
	4	Fallow	--	--	10.9	93.5	125
Nonmined	20	Cropped	10.8	--	13.5	72.4	124
	36	Fallow	--	--	8.0	6.8	96.6
					Corn leaf		
Mine spoil	3	Cropped	92.0	--	89.2	76.9	
Nonmined	20	Cropped	20.4	--	27.4	--	
					Grain		
Mine spoil	3	Cropped	31.0	27.8	28.0	39.4	
Nonmined	20	Cropped	23.6	23.1	32.3	27.2[b]	

Source: Peterson, Pietz and Lue-Hing (1979). Reproduced by permission of Penn State Press.

[a] Soil Zn represents that fraction extractable with 0.1 N HCl from 0- to 15-cm samples by three successive 5-minute extractions using 1:10 soil/exteactant ratio.

[b] Field 20 contained soybeans in 1975.

Table 19.23. Copper concentrations (ug Cu/g dry basis) of surface soils and crops for typical sludge-amended mine spoil and unmined fields at Fulton County, Illinois land reclamation site.

Land Type	Field Number	Agricultural Use	Year 1972	1973	1974	1975	1976
					Soil[a]		
Mine spoil	3	Cropped	--	11.4	9.84	31.6	42.2
	4	Fallow	--	--	5.40	38.2	42.8
Unmined	20	Cropped	3.11	--	4.37	21.9	32.6
	36	Fallow	--	--	2.67	2.97	30.0
					Corn leaf		
Mine spoil	3	Cropped	18.0	--	23.9	15.5	
Unmined	20	Cropped	7.03	--	10.4	--	
					Grain		
Mine spoil	3	Cropped	2.73	2.81	2.30	2.99	
Unmined	20	Cropped	1.41	2.98	5.14	14.0[b]	

Source: Peterson, Pietz and Lue-Hing (1979). Reprinted by permission of Penn State Press.

[a] Soil Cu represents that fraction extractable with 0.1N HCl from 0- to 15-cm soil samples by three successive 5-minute extractions using 1:10 soil:extractant ratio.

[b] Field 20 contained soybeans in 1975.

Table 19.24. Average concentrations (µg/g) of heavy metal constituents in foliar samples of Phalaris arundinacea, in Pennsylvania.

Treatment (t/ha)	1974			1975			1976		
	NI	W	E	NI	W	E	NI	W	E
Cu									
0	6.9 a[a]	5.8 a	6.8 a	9.9 a	13.0 a	8.8 a	9.6 a	7.4 a	5.9 a
40	13.9 a	13.7 ab	15.7 b	10.1 a	10.6 a	10.0 a	9.0 a	10.9 b	9.5 ab
75	16.3 a	17.8 b	15.8 b	12.8 a	12.7 a	12.1 a	11.2 a	14.3 c	12.6 b
150	18.9 a	31.4 c	21.5 c	15.4 a	13.9 a	13.5 a	12.3 a	12.0 bc	11.1 b
Zn									
0	33.2 a	31.1 a	36.9 a	48.0 a	61.4 a	46.7 a	37.4 a	48.4 a	29.6 a
40	40.0 a	51.8 a	66.6 b	46.0 a	57.9 a	44.7 a	47.0 ab	45.8 a	39.5 a
75	42.8 a	76.1 b	60.4 b	61.6 a	57.0 a	64.7 a	59.8 bc	61.5 a	51.7 a
150	79.2 b	74.6 b	70.8 b	69.3 a	72.7 a	81.1 a	65.6 c	56.1 a	98.3 b
Cd									
0	0.23 ab	0.23 a	0.26 a	0.23 a	0.16 a	0.21 a	0.16 a	0.16 a	0.11 a
40	0.14 b	0.20 a	0.26 a	0.14 a	0.14 a	0.20 a	0.06 a	0.22 a	0.11 a
75	0.36 a	0.37 a	0.31 a	0.18 a	0.13 a	0.16 a	0.12 a	0.11 a	0.15 a
150	0.54 c	0.54 a	0.54 a	0.23 a	0.20 a	0.15 a	0.11 a	0.08 a	0.12 a
Ni									
0	9.2 a	6.1 a	5.6 a	6.9 a	7.4 a	5.7 a	7.4 a	5.8 a	4.0 a
40	5.5 a	5.4 a	4.5 a	3.3 b	3.5 b	2.8 b	3.8 a	4.1 a	2.8 a
75	6.1 a	3.9 a	5.2 a	4.0 b	2.5 b	2.9 b	4.1 a	3.2 a	2.7 a
150	6.2 a	4.6 a	4.7 a	4.1 b	3.4 b	3.6 b	3.6 a	3.6 a	2.9 a
Cr									
0	0.7 a	0.8 a	1.1 a	0.5 a	0.8 a	0.8 a	0.4 a	0.8 a	0.4 a
40	0.7 a	0.7 a	0.7 a	0.3 a	0.6 a	0.6 b	0.4 a	0.6 a	0.4 a
75	0.6 a	0.8 a	0.8 a	0.4 a	0.4 a	0.5 b	0.5 a	0.4 a	0.4 a
150	0.7 a	1.0 a	0.7 a	0.5 a	0.6 a	0.7 ab	0.5 a	0.5 a	0.4 a
Pb									
0	10.2 a	9.8 a	7.6 a	15.0 a	8.1 a	11.6 a	12.1 a	10.3 a	5.9 a
40	5.1 b	5.4 a	6.9 a	10.5 a	7.0 a	10.4 a	15.5 a	17.4 a	11.3 a
75	4.5 b	8.1 a	5.2 a	7.3 a	6.4 a	8.1 a	8.5 a	15.7 a	17.4 a
150	4.7 b	9.7 a	5.5 a	10.5 a	7.9 a	6.9 a	9.3 a	10.5 a	7.5 a
Co									
0	1.6 a	1.1 a	1.5 a	1.3 a	1.4 a	1.6 a	1.0 a	1.3 a	1.0 a
40	1.2 a	1.4 a	1.7 a	1.2 a	1.1 a	1.1 a	0.8 a	1.1 a	0.8 a
75	1.4 a	1.7 a	1.5 a	1.2 a	1.1 a	1.3 a	1.1 a	1.1 a	1.1 a
150	1.3 a	1.6 a	1.4 a	1.2 a	1.3 a	1.0 a	1.3 a	1.2 a	1.1 a

Source: Kerr, Sopper and Edgerton (1979). Reprinted by permission of Penn State Press.

[a] Means of the four sludge treatments followed by the same letter are not significantly different from each other at the 0.05 level of significance.

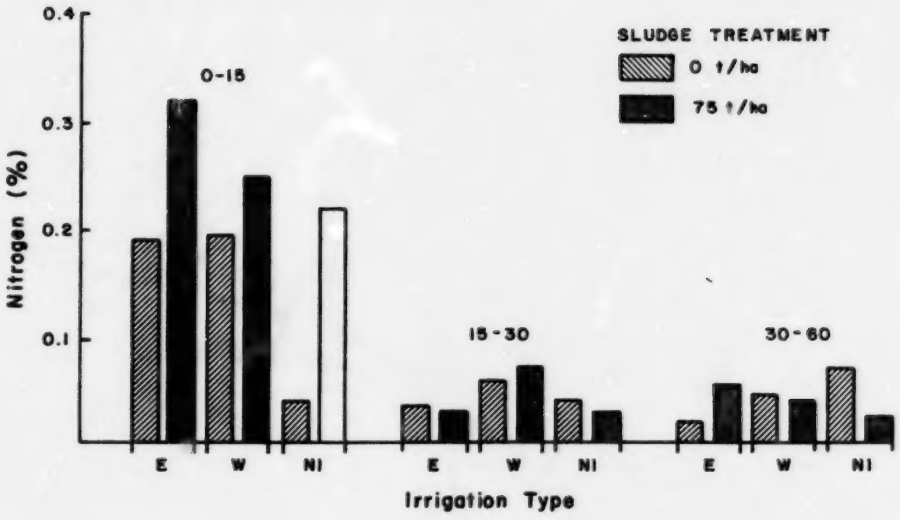

Figure 19.3. Average percentage of Kjeldahl nitrogen in the refuse at various soil depths for the 0 and 75 dry ton/ha sludge applications.

Source: Kerr, Sopper and Edgerton (1979)
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Table 19.25. Chemical analysis of refuse bank for heavy metal constituents before and after sludge treatments in Pennsylvania.

Sludge (t/ha) and Refuse	Treatment Depth	Cu (ug/g)	Zn (ug/g)	Cr (ug/g)	Pb (ug/g)	Co (ug/g)	Cd (ug/g)	Ni (ug/g)
1974								
Depth 0 to 30 cm								
NI	0	7.0	3.5	0.12	0.33	0.36	0.02	1.21
	75	6.5	2.0	0.16	0.80	0.14	0.02	0.53
W	0	7.0	4.5	0.11	1.44	0.65	0.03	0.73
	75	5.5	5.5	0.14	1.00	0.67	0.02	0.89
E	0	4.5	4.0	0.08	0.62	0.53	0.02	0.69
	75	5.0	4.0	0.08	0.53	0.35	0.03	1.02
Depth 30 to 60 cm								
NI	0	6.5	3.5	0.08	0.55	0.16	0.02	0.44
	75	7.0	3.0	0.11	0.98	0.25	0.03	0.63
W	0	8.5	13.5	0.14	2.07	1.01	0.03	2.19
	75	5.5	4.5	0.17	0.69	0.54	0.02	1.01
E	0	5.0	4.5	0.11	1.10	0.40	0.02	0.45
	75	7.5	3.5	0.09	0.77	0.33	0.02	1.02
1976								
Depth 0 to 15 cm								
NI	0	3.5	2.0	0.20	4.48	0.39	0.07	0.93
	75	72.0	118.0	4.49	71.41	1.10	0.85	3.79
W	0	2.0	5.5	0.14	1.75	0.80	0.06	1.47
	75	44.5	99.5	1.41	15.34	1.34	0.83	2.81
E	0	3.0	13.0	0.22	0.91	1.02	0.10	2.07
	75	58.0	104.5	2.41	21.87	1.27	0.51	3.31
Depth 15 to 30 cm								
NI	0	4.0	1.5	0.15	1.38	0.33	0.02	0.74
	75	2.0	3.5	0.13	0.63	0.47	0.02	0.81
W	0	2.0	7.0	0.14	1.30	0.56	0.03	0.82
	75	2.5	4.5	0.14	1.07	0.50	0.05	1.03
E	0	1.5	3.0	0.08	0.58	0.43	0.02	0.60
	75	3.0	2.0	0.09	1.12	0.47	0.03	0.44
Depth 30 to 60 cm								
NI	0	2.0	2.0	0.11	0.79	0.45	0.01	1.00
	75	2.5	6.5	0.20	1.83	0.65	0.06	0.79
W	0	3.0	12.5	0.26	1.21	0.79	0.02	0.96
	75	2.0	4.5	0.16	0.77	0.52	0.02	0.72
E	0	2.0	5.5	0.16	0.85	0.76	0.02	0.92
	75	2.5	1.0	0.09	0.77	0.24	0.03	0.54
Normal range in Pennsylvania soils		2 to 100	10 to 300	5 to 1000	2 to 200	1 to 40	0.01 to 0.70	5 to 500

Source: Kerr, Sopper and Edgerton (1979). Reprinted by permission of Penn State Press.

Infiltration and water-holding capacity of mine spoil has been reportedly improved by applying sewage sludge. Loebel, Lowe and Beauchamp (1978) found an increase in water content of sewage amended coarse textured spoils. Organic matter content was increased and bulk density was lowered as well. Peterson and Gschwind (1972) using 7.5 cm diameter x 45 cm columns of spoils and anaerobically digested liquid sludge, found that water was absorbed faster in sludge treated columns than in spoil alone. Also, there was greater leachate recovery from treated columns, indicating less evaporation losses. Similar observations in the field were made by Sutton and Vimmerstedt (1973). Sewage sludge from Caldswell, Ohio applied to mine spoil increased rainfall infiltration, reducing runoff and erosion. Hortenstine and Rothwell (1972) showed that the water-holding capabilities of phosphate and tailings sand in Florida were increased by adding municipal compost (Table 19.26).

Edgerton and Sopper (1974), in a study of the effect of effluent and sludge on growth of grasses and legumes on bituminous coal strip mine spoils in Pennsylvania, found the surface and subsurface temperatures of the spoils were unaffected by the treatment.

Their study was conducted in lysimeters 1.2 x 9.8 x 1.2 m deep. Leachate from the non-treated spoil had the highest heavy metal and the lowest nitrogen concentrations. Leachate from the highest effluent and sludge treatments had the lowest metal concentrations.

McCormick and Borden (1973) determined the chemical composition of percolate obtained after sewage and sludge was applied to an acidic spoil material associated with the Brookville coal seam near Kylertown, Pennsylvania. The material was placed in lysimeters 30 cm in diameter and 91 cm deep. A weekly 5 cm application of water served as the control. Six other treatments had 5 cm of synthetic sewage effluent applied each week where 0 to 20 cm of sludge had been applied on top or mixed into the top 15 or 30 cm of spoil. One of the six treatments was dressed with the equivalent of 18 t/ha of dolomitic limestone incorporated into the top 15 cm of spoil.

Table 19.26. The influence of municipal compost amendment on tailings sand water retention of tailings sand in Florida.

Compost t/ha	Soil Moisture (θv)		
	0.10 atm	0.33 atm	15.00 atm
	%		
0	2.18	2.17	1.86
35	3.17	2.79	2.15
70	3.42	3.11	3.02

Source: Adapted from Hortenstine and Rothwell (1972), Journal of Environmental Quality. Volume 1, 1972, pages 415-418 by permission of the American Society of Agronomy, Crop Science Society of America, Soil Science Society of America.

In 26 weeks, the pH of the percolate in the 10 or 20 cm sludge treatment increased from 4.1 to 6.5 and levelled off at 7.2 between the 30th and 45th weeks. Concentrations of Ca in all treatments were below that of the applied effluent. In the control, effluent only, and effluent plus lime treatments, K concentration was below that of the control, but where sludge was applied, K increased for the first seven weeks and then levelled off. Treatment without sludge or with only 5 cm of sludge had colourless percolate. Heavier sludge treatment percolates became increasingly discoloured and odorous from ammonia.

In experiments to reclaim extremely acidic mine spoil from Pennsylvania, Sopper and Kardos (1971) found that the pH of the percolate increased from 2.2 or 2.8 to 4.06 in 24 weeks as a result of weekly application of 5 cm of effluent plus 5 cm of sludge. The percolate from this treatment was also highest in P and NO_3 and lowest in Al and Mn.

Using methods similar to those in Edgerton and Sopper (1974) and Sopper and Kardos (1971), Sopper, Kardos and Edgerton (1974) also reported on the effect of sewage effluent and sludge application leachate from very acidic Pennsylvania spoil (Table 19.27). As with previous work, high effluent plus sludge (5 cm/wk) application increased spoil pH. This treatment also produced the highest NO_3, NH_4, and organic N concentrations. Conversely, P and K levels were unaffected. Although the control had the highest levels of Fe, and the highest sludge plus effluent treatment had the lowest Fe level, iron and Al levels in the leachate were all above the reported toxic level of 1.0 mg/L.

In separate lysimeter experiments, Doyle (1976) added effluent (Table 19.28) and sewage sludge (Table 19.29) to very acidic spoil of pH 2 to 3 from northern Appalachia. Nitrogen levels in lysimeter leachate reached 20 mg/L (Table 19.30) whereas the levels of metals such as Fe, Al, Cu, and Zn decreased. The P level was unaffected (Table 19.30). Presumably phosphate precipitation lowered Fe, Al, Ca, Mg, and B levels in the leachate. There may be some Mn leaching in response to

Table 19.27. Chemical composition of leachate samples taken below the surface of Pennsylvania spoil.[a]

	mg/L		
	Control	1 + 1[b]	2 + 2[c]
SO_4	421	246	101
NO_3-N	1.2	2.7	6.2
NH_4-N	2.2	22.9	28.9
Organic N	6.5	15.2	15.9
Orthophosphate-P	0.14	0.10	0.12
Ca	30.1	21.9	16.8
Mg	45.1	28.2	14.4
Mn	15.2	6.4	2.9
Fe	78.8	58.0	7.0
K	50.4	49.4	43.2
pH	2.70	2.70	3.00

Source: Sopper, Kardos and Edgerton (1974).

[a] Values given are averages of date for treatment vegetated with grass and legumes.

[b] 1 inch each of effluent and sludge per week.

[c] 2 inches each of effluent and sludge per week.

Table 19.28. Chemical composition of sewage effluent.

Constituent	Range[a]		Mean
	Minimum	Maximum	
pH	6.70	7.99	7.33
Organic Nitrogen[b]	1.2	3.8	1.7
Ammonium-N	2.8	7.1	5.3
Nitrate-N	6.8	17.5	13.1
Orthophosphate-P	4.8	6.2	5.5
Total acidity[c]	0.1	0.3	0.2
Sulfate Sulphur	11.5	18.5	16.0
Potassium	2.0	68.7	23.6
Calcim	23.8	46.5	34.2
Magnesium	12.6	21.2	17.9
Manganese	0.0	0.1	0.1
Iron	0.5	2.0	0.9
Copper	0.1	0.3	0.2
Boron	0.1	0.3	0.2
Aluminum	0.3	1.0	0.7
Zinc	0.2	0.5	0.4
Sodium	33.4	44.5	38.2

Source: Doyle (1976).

[a] All values in mg/L except pH and total acidity.

[b] Does not include ammoniacal nitrogen.

[c] Expressed in meq/L as hydrogen.

Table 19.29. Chemical composition of liquid digested sludge.

Constituent	Range[a]		Mean
	Minimum	Maximum	
pH	7.30	7.52	7.41
Organic Nitrogen[b]	69.0	644.0	195.1
Ammonium-N	127.0	500.0	300.9
Nitrate-N	2.3	4.4	3.1
Phosphorus[c]	69.0	272.1	118.3
Potassium	75.6	191.6	136.1
Calcium	33.2	290.8	82.2
Magnesium	10.2	72.5	27.1
Manganese	0.3	8.9	1.9
Iron	1.5	90.2	17.7
Copper	0.4	8.9	2.4
Boron	0.2	2.1	1.0
Aluminum	2.9	95.4	18.7
Zinc	0.8	11.7	3.5
Sodium	25.6	74.3	48.5
Total Dry Solids	850	8190	2220
Volatile Solids	440	5470	1390

Source: Doyle (1976).
[a] All values in mg/L except pH.
[b] Does not include ammoniacal nitrogen.
[c] Total P by dry ashing plus 6N HCl.

Table 19.30. Mean chemical composition of leachate samples from sewage amended Appalachia spoils.

Treatment	Vegetation Type	pH	Mean Concentrations of Leachate					
			Sulfates (SO_4) mg/L	Nitrates (NO_3-N) mg/L	Ammonium (NH_4-N) mg/L	Organic Nitrogen mg/L	Orthophos-phate(P) mg/L	Total Acidity meq/L as H
1 + 1	Grass	2.64	312	2.2	17.6	14.9	0.13	15.8
	Legume	2.77	179	3.2	27.2	15.5	0.07	6.9
2 + 2	Grass	3.08	95	6.9	29.9	16.3	0.17	3.3
	Legume	2.91	107	5.5	26.4	15.5	0.07	4.0
Control	Grass	2.71	442	1.2	1.9	5.4	0.11	18.1
	Legume	2.68	400	1.3	2.5	7.6	0.17	17.7

Source: Doyle (1976).

effluent and sludge amendment. Soil pH increased to near neutral levels close to the spoil surface but remained acidic at depth.

In studies on the PALZO tract in Illinois, Jones and Cunningham (1979) found that sludge reduced the concentration of metals in leachate waters as spoil pH increased. Thus heavy metal and P concentrations decreased with sludge applications up to 672 dry t/ha (Table 19.31). Sludge amendment also reduced Fe, Al, and SO_4 levels in leachates (Table 19.31). Conversely, Cl_2 and NO_3 losses increased. The author suggested many of these changes were due to the fact that sludge amendment reduced pyrite oxidation in the spoils.

Kerr, Sopper and Edgerton (1979) studied amendment of burned anthracite spoil with a combination of treated sewage effluent and domestic sewage. The effluent loading rates are summarized in Tables 19.10 and 19.11. Studies on leachate quality collected from suction lysimeters installed at 90 cm soil depth showed a rapid decrease to near background levels within two years. Only the plot amended at 150 t/ha produced NO_3 levels exceeding 10 mg/L, the human health hazard threshold (Table 19.32).

In the studies of Peterson, Pietz and Lue-Hing (1979) the detectable impact of sludge amendments (Table 19.15) on groundwater quality was minimal (Tables 19.16 and 19.33). As previously mentioned, nitrate levels increased but not in excess of 10 ppm, where a health hazard exists. There are some apparent increases in some mobile anions and cations such as $SO_4^=$, Ca, and Mn, and decreases in others such as Na (Table 19.33).

In experiments in northeastern Minnesota, Brooks, Borovsky and Mace (1979) experimented with application of secondary sewage effluent on sandy loam textured iron ore spoil. They studied the efficiency of nutrient removal, the risk of groundwater contamination and the enhancement of spoil fertility. The effluent loading rates are described in Table 19.8. At one site, after about 20 days of effluent irrigation of 4 to 6 cm/wk, P and Cl_2 in leachates were marginally increased with the Cl_2 due to sampling technique (Table 19.34). Conversely after about 60 days of effluent irrigation NO_3 + NO_2 levels at 120 cm soil depth

Table 19.31. Observed differences in mean concentration (mg/L) of measured water quality parameters in leachate from a sludge-treated western watershed at Palzo[a], Illinois.

Element	Before Treatment	During Treatment	% Difference
Cl	6.7	19.6	+191
Cu	3.803	0.908	-76
Cr	0.986	0.593	-40
Cd	1.341	0.964	-28
Al	1809	1418	-21
Fe	2977	2433	-19
Zn	36	30	-18
Mn	166	140	-15

Source: Jones and Cunningham (1979). Reprinted by permission of Penn State Press.

[a] Mean values for semi-monthly observations were tested by analysis of variance comparing the May 1974 through April 1975 interval with the May 1975 through April 1976 interval at a level of 0.05. No other measured parameters yielded significant differences by this test. All values are total ion determinations.

Table 19.32. Mean concentration of chemical constituents in the 1976 leachate samples from treated Pennsylvania spoils.

Treatment	(t/ha)	pH	Ortho P (mg/L)	NO_3-N (mg/L)	NH_4-N (mg/L)	Org N (mg/L)	Cu (ppb)	Zn (ppb)	Cd (ppb)	Ni (ppb)	Pb (pbb)	Co (ppb)
NI	0	5.8	0.07 a[a]	0.9 a	0.10 a	0.04 a	13 a	373 a	1.2 a	142 a	68 a	76 a
	40	6.4	0.10 a	1.2 a	0.04 b	0.05 a	10 a	384 a	1.0 a	79 a	58 a	59 a
	75	7.0	0.48 b	6.4 b	0.03 b	0.23 b	6 a	281 ab	0.2 b	39 b	83 a	27 b
	150	7.5	0.09 a	15.1 c	0.03 b	0.13 c	14 a	146 b	0.3 b	54 b	76 a	34 b
W	0	6.5	0.10 a	0.8 a	0.02 a	0.03 a	5 a	130 a	0.1 a	30 a	66 a	27 a
	40	6.8	0.22 b	3.9 b	0.03 a	0.02 a	14 a	116 a	0.1 a	31 a	73 a	35 a
	75	6.7	0.33 c	5.8 c	0.04 a	0.06 a	5 a	134 a	0.2 a	31 a	72 a	30 a
	150	5.2	0.04 d	8.0 d	0.03 a	0.03 a	31 b	749 b	4.8 b	214 b	87 a	100 b
E	0	6.4	0.21 a	2.2 a	0.06 a	0.03 a	15 a	195 a	2.3 a	61 a	95 a	44 a
	40	6.5	0.31 a	3.9 b	0.09 a	0.05 a	6 a	231 a	1.1 a	63 a	70 a	36 a
	75	6.8	0.45 a	7.7 c	0.04 a	0.02 a	11 a	190 a	1.7 a	69 a	84 a	36 a
	150	6.8	1.39 b	6.0 d	0.05 a	0.13 b	13 a	195 a	0.6 a	57 a	78 a	35 a

Source: Kerr, Sopper and Edgerton (1979). Reprinted by permission of Penn State Press.

[a] Means of the four sludge treatments followed by the same letter are not significantly different from each other at the 0.05 level of significance.

Table 19.33. Water quality of two watershed reservoirs, R3 and R4, at the Fulton County, Illinois, sludge application site (mean of 12 monthly grab samplings/year).

Reservoir:	R3 (mg/L)			R4 (mg/L)		
Year: Constituent[b]	1972	1974	1976	1972[a]	1974	1976
Total P	0.13	0.09	0.14	0.12	0.09	0.13
Cl^-	36	21	22	12	36	14
SO_4^{2-}	467	711	624	164	219	287
Kjeldahl N	<1.0	1.0	1.0	1.4	0.8	1.0
NH_3-N	0.2	0.4	0.2	0.4	0.2	0.1
$(NO_2 + NO_3)$-N	0.09	0.65	1.26	0.04	0.53	0.22
Alkalinity as $CaCO_3$	283	312	288	250	178	173
K	7.6	7.3	8.7	5.3	2.7	3.6
Na	259	174	193	23	13	18
Ca	116	175	148	109	121	112
Mg	100	128	100	64	51	57
Zn	0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Cd	0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cu	0.08	0.02	0.08	0.12	<0.01	<0.01
Cr	<0.02	<0.02	<0.02	<0.03	<0.02	<0.02
Ni	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Mn	0.16	0.30	0.23	0.41	0.64	0.51
Pb	0.03	0.07	0.02	<0.01	0.04	0.02
Fe	0.4	0.1	0.3	0.9	1.6	1.3
Al		<1.8	<1.0	<1.0	1.1	<1.0
Hg (µg/l)	0.1	0.2	<0.1	0.4	0.3	<0.1
TSS		9.4	14		58.4	56
TDS		1669	1743		556	802
FC (geometric mean counts/100 mL)	5	9	5	128	28	7
pH range	6.8 to 8.5	7.7 to 8.3	7.8 to 8.5	7.2 to 8.4	7.6 to 8.3	7.9 to 8.5
EC[c] (umhos/cm)	1727	1856	1575	938	833	744

Source: Peterson, Pietz and Lue-Hing (1979)

[a] Mean of monthly grab samples for July to December.

[b] Analysis of variance showed significant yearly differences at the 0.01 level for the total P, Cl^-, and $(NO_2 + NO_3)$-N on R3 and for NH_3-N for R4. The $LSD_{0.05}$ was 0.07 mg P/L, 10 mg Cl/L, and 0.72 mg $(NO_2 + NO_3)$-N/L for R3 and 0.13 mg NH_3-N/L for R4.

[c] Electrical conductivity.

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Table 19.34. Average effluent and soil percolate concentrations (mg/L) 19 days after the beginning of irrigation of a northeastern Minnesota iron ore spoil.

		Treatment											
		Control Depth			Minimum Depth			Medium Depth			Maximum Depth		
Nutrients	Effluent	30 cm	60 cm	120 cm	30 cm	60 cm	120 cm	30 cm	60 cm	120 cm	30 cm	60 cm	120 cm
$(NO_3 + NO_2)$-N	0.56	3.53	1.30	0.19	10.00	2.98	0.27	6.42	2.39	0.50	0.34	0.54	<0.01
Total Kjeldahl N	10.22	4.37	1.36	1.69	3.00	2.22	2.99	2.39	1.47	2.17	4.47	1.93	2.31
Total P[a]	2.16	0.02	0.02	0.02	0.07	0.02	0.08	0.07	0.05	0.06	0.03	0.04	0.01
Ca	35.6	98.3	94.5	86.9	101.7	67.7	69.3	92.4	69.5	79.6	119.6	98.1	71.0
Mg	16.6	63.6	85.2	70.7	81.2	55.3	62.0	87.0	59.6	78.8	114.4	91.8	79.9
Na	45.5	21.97	6.65	6.42	21.10	6.62	5.92	28.82	11.25	7.75	15.52	9.45	6.77
K	7.61	7.55	3.80	3.42	6.77	3.10	2.90	8.62	4.75	3.62	11.77	4.50	3.35
Cl[a]	68.2	171.9	29.9	11.3	80.3	27.0	16.5	129.2	43.3	26.1	52.7	58.8	30.7

Source: Brooks, Borovsky and Hace (1979). Reprinted by permission of Penn State Press.

[a] Whole-plot treatment means differed significantly (0.05).

decreased due to effluent irrigation, probably due to enhanced denitrification (Table 19.35). It is apparent organic-N (measured as total N) is being converted to NO_3 by nitrification but not denitrified, thus resulting in elevated NO_3 levels at depth.

The results from a second site were similar except that P levels at depth (100 cm) were less in the effluent irrigated sites, especially at high loading rates, compared to the control sites (Table 19.36). Magnesium also tended to be lower in effluent irrigated sites probably due to P precipitation reactions.

Kardos et al. (1979) applied different loadings of sewage sludge and effluent to Pennsylvania soft strip mine and hard shaft mine coal spoil in controlled field experiments. Tables 19.37 and 19.38 show the amendment loading rates and composition, respectively. From studying the leachate from the bituminous strip mine spoil plots it is clear heavy amendment with alkaline effluent and sludge will eventually increase leachate pH (Table 19.39). Nitrogen levels in the leachate also increased although most of the N in the amendments was converted to organic form. The acid spoil conditions limited nitrification; thus, most of the N lost to leaching was as NH_4-N (Table 19.39). As the pH rose, however, nitrification probably increased, thus accounting for increased NO_3 levels in leachate with time.

Conversely, toxic levels of Mn and Al in spoil leachate were markedly reduced by effluent and sludge amendment (Table 19.39) presumably due to increased spoil pH and P precipitation.

Leachates from the anthracite spoil showed similar trends in response to sludge and effluent amendment. Table 19.40 shows how markedly the pH is influenced near the spoil surface compared to greater depths in the profile. The anthracite spoil had less metal toxicity than the bituminous spoil and this toxicity was similarily reduced by sludge and effluent amendment (Table 19.41).

The high levels of P in the effluent were precipitated with Fe and Al from the spoil. This fixed most of the P near the spoil surface (Table 19.42) and substantially reduced extractable Fe and Al levels especially at high amendment rates near the spoil surface (Tables 19.43

Table 19.35. Average effluent and soil percolate concentrations (mg/L) post irrigation (9/4/75) on a northeastern Minnesota iron ore spoil.

		Treatment											
		Control Depth			Minimum Depth			Medium Depth			Maximum Depth		
Nutrients	Effluent	30 cm	60 cm	120 cm	30 cm	60 cm	120 cm	30 cm	60 cm	120 cm	30 cm	60 cm	120 cm
$(NO_3 + NO_2)$-N[a]	0.56	11.11	2.73	0.59	7.87	3.83	0.38	7.71	5.22	0.80	1.04	0.79	0.01
Total Kjeldahl N	10.22	0.57	0.80	1.25	1.73	1.53	1.14	0.69	1.12	1.00	2.91	1.52	1.17
Total P	2.16	0.03	0.02	0.02	0.04	0.02	0.11	0.06	0.02	0.02	0.03	0.05	0.02
Ca	35.6	88.2	102.6	107.6	114.6	76.0	80.7	99.3	75.4	92.5	126.4	92.0	98.5
Mg	16.6	48.8	61.1	70.8	59.7	51.9	60.6	71.6	56.1	79.2	94.7	72.6	88.2
Na	45.5	15.6	6.27	6.90	16.22	6.42	6.37	19.37	8.15	5.92	25.32	14.90	10.05
K	7.61	5.05	3.40	3.82	5.70	3.10	2.95	4.45	3.30	3.42	10.45	4.72	3.75
Cl	68.2	105.0	15.6	10.3	84.2	34.5	15.2	74.7	40.6	43.6	90.2	65.8	53.3

Source: Brooks, Borovsky and Mace (1979). Reprinted by permission of Penn State Press.

[a] Maximum treatment differed significantly (0.05) from minimum and medium treatments.

Table 19.36. Average effluent and soil percolate concentrations, post irrigation (9/16/76) on a northeastern Minnesota iron ore spoil.

Nutrient	Effluent	Treatment and Depth					
		Control		5 cm/wk		10 cm/wk	
		50	100	50	100	50	100
(NO_3+NO_2)-N (mg/L)	0.2	NA	68.01a[a]	18.62a[b]	14.31b	14.04a	16.26b
Total Kjeldahl N (mg/L)	15.4	NA	0.59a	1.92a	1.80a	2.00a	2.18a
NH_4 (mg/L)	6.93	NA	0.212a	0.086a	0.135a	0.078b	0.980a
Total P (mg/L)	3.58	NA	0.031a	0.010a	0.015b	0.015b	0.010c
Ca (mg/L)	25.2	NA	292.6a	160.3a	161.30a	163.8a	171.3a
Mg (mg/L)	10.2	NA	119.4a	64.65a	71.6b	64.45a	72.8b
Na (mg/L)	50.3	NA	41.80a	42.15a	38.07a	40.77a	45.15a
K (mg/L)	7.06	NA	27.30a	24.77a	25.77a	24.17a	26.92a
Cl (mg/L)	57.2	NA	47.33a	91.67a	71.92a	84.87a	75.10a
Specific condition (μmhos/cm)	538	NA	2179a	1468a	1453a	1417a	1520a
Total alkalinity (mg $CaCO_3$/L)	73.9	NA	271.6a	310.0a	384.5a	326.3a	398.0a

Source: Brooks, Borovsky and Mace (1979). Reprinted by permission of Penn State Press.

[a] Treatment means within a depth followed by a common letter do not significantly (0.05) differ.

[b] Means represent four observations.

Table 19.37. Average chemical composition (mg/L) of sewage effluent and liquid digested sludge used in treatment of bituminous strip mine spoil and anthracite refuse in Pennsylvania.

Constituent	Bituminous Strip Mine Spoil		Anthracite Refuse	
	Effluent	Liquid Sludge	Effluent	Liquid Sludge
Nitrate N	13.1	3.1	15.5	5.1
Ammoniacal N	5.3	300.9	10.1	585.3
Organic N	1.7	195.1	1.5	242.7
Orthophosphate P	5.5	--	5.18	--
Total P	--	118.3	--	188.8
Potassium	23.6	136.1	9.9	9.0
Calcium	34.2	82.2	26.6	122.3
Magnesium	17.9	27.1	16.0	51.0
Sodium	38.2	48.5	38.8	44.0
Aluminum	0.7	18.7	0.88	33.3
Manganese	0.1	1.9	0.16	2.5
Iron	0.9	17.7	0.39	36.0
Copper	0.2	2.4	0.08	4.26
Zinc	0.4	3.5	0.25	5.21
Total dry solids	--	2220	--	3905
Volatile solids	--	1390	--	2428
pH	7.3	7.4	7.8	7.4

Source: Kardos et al. (1979). Reproduced by permission of Penn State Press.

Table 19.38. Application rates of effluent and liquid sludge treatments (cm) on a Pennsylvania anthracite mine spoil.

Box Number	Code	Application at Weekly Intervals				Total Applied		Total Waste Hydraulic Load
		Effluent		Sludge				
		5/12-8/8	8/16-9/27	5/12-8/9	8/16-9/27	Effluent	Sludge	
1	Control	0	0	0	0	0	0	0
2	2E	5.0	5.0	0	0	96.5	0	96.5
3	1E + 1S	2.5	2.5	2.5	0	48.3	25.4	73.7
4	2E + 2S	5.0	5.0	5.0	0	96.5	50.8	147.3

Source: Kardos et al. (1979). Reproduced by permission of Penn State Press.

Table 19.39. Mean chemical composition of leachate samples taken 107 cm below the Pennsylvania bituminous spoil surface.

Treatment	pH	Concentration (mg/L)			
		NO_3-N	NH_4-N	Al	Mn
Control	2.70 a[a]	1.2 a	2.2 a	96.1 c	15.2 c
1E + 1S	2.71 a	2.7 b	22.6 b	40.1 b	6.4 b
2E + 2S	2.99b	6.2 c	28.1c	12.9 a	2.9 a

Source: Kardos et al. (1979). Reprinted by permission of Penn State Press.

[a] By Duncan's modified least significance test, treatment means for each parameter followed by the same letter are not significantly different at the 99% confidence level.

Table 19.40. Mean pH of the Pennsylvania anthracite refuse leachate at the 15-cm and 107-cm depth for the 19-week test period.

Treatment	Depth	
	15 cm	107 cm
Control	3.16 c[a]	3.58 c
2E	6.28 ab	3.67 bc
1E + 1S	5.38 b	3.76 b
2E + 2S	7.39 a	4.12 a

Source: Kardos et al. (1979). Reprinted by permission of Penn State Press.

[a] Treatment means at a particular depth followed by the same letter are not significantly different from each other: P = 0.05.

Table 19.41. Mean iron, aluminum, and manganese concentrations (mg/L) in leachate from the Pennsylvania anthracite refuse at the 107-cm depth for the 19-week test period.

Treatment	Fe	Al	Mn
Control	3.3 a[a]	40.3 a	7.8 a
2E	3.0 a	11.5 b	2.6 c
1E + 1S	2.9 a	31.9 a	4.4 b
2E + 2S	1.7 a	16.8 b	2.9 c

Source: Kardos et al. (1979). Reprinted by permission of Penn State Press.

[a] Treatment means for a particular constituent followed by the same letter are not significantly different from each other; P = 0.05.

Table 19.42. Bray phosphorus in Pennsylvania anthracite refuse at three depths in various treatments.

Treatment	Total P Applied (kg/ha)	Bray Phosphorus (ug P/g refuse)		
		15 cm	46 cm	76 cm
2E + 2S	1009.2	38.90 a[a]	7.66 a	6.99 a
1E + 1S	504.6	17.25 ab	3.24 b	2.79 b
2E	50.1	12.80 b	2.00 b	3.49 b
Control	0	2.25 b	1.71 b	2.42 b

Source: Kardos et al. (1979). Reprinted by permission of Penn State Press.

[a] Values at a particular depth followed by the same letter are not significantly different at the 0.05 level of confidence.

Table 19.43. KCl extractable iron in Pennsylvania anthracite refuse at three depths in various treatments.

Treatment	KCl Extractable Iron (ug Fe/g refuse)		
	15 cm	46 cm	76 cm
Control	60.0 a[a]	50.7 a	57.7 a
2E	20.8 b	32.4 b	33.9 a
1E + 1S	18.2 b	25.3 b	32.6 a
2E + 2S	6.7 b	10.4 c	34.4 a

Source: Kardos et al. (1979). Reprinted by permission of Penn State Press.

[a] Values at a particular depth followed by the same letter are not significantly different at the 0.05 level of confidence.

Table 19.44. KCl extractable aluminum in Pennsylvania anthracite refuse at three depths in various treatments.

Treatment	KCl Extractable Al (ug Al/g refuse)		
	15 cm	46 cm	76 cm
Control	222.6 a[a]	205.7 a	205.1 a
2E	152.5 b	181.4 ab	200.6 a
1E + 1S	94.7 c	135.5 bc	149.3 ab
2E + 2S	68.4 c	81.4 c	136.7 b

Source: Kardos et al. (1979). Reprinted by permission of Penn State Press.

[a] Values at a particular depth followed by the same letter are not significantly different at the 0.05 level of confidence.

and 19.44). Extractable Mn levels were also reduced although the effect was of a lesser magnitude.

19.5 EFFECTS ON BIOTA

19.5.1 Crop Establishment and Adapted Species

Most reports indicate sewage sludge and effluents were beneficial to the establishement of vegetation on mine spoils. Sites were primarily from Illinois, near Chicago, and from Pennsylvania.

One exception by Dean and Havens (1971) dealt with the addition of Coherex, a resinous adhesive combined with sewage sludge or refuse compost application to copper concentrate tailings in Nevada. Five centimetre layers of sludge were placed at depths of 8, 18, 28, and 38 cm below the surface of tailings material 46 cm deep in barrels. In another series of tests, the equivalent of 34 t/ha of sewage sludge was mixed into the top 7 cm of tailings. Agropyron cristatum, Medicago sativa cv. Ranger, and Secale cereale were planted in both series of tests with Hordeum vulgare as a fourth species in the first series and a small transplanted Lycopersicon esculentum in the other series.

Where sludge was not mixed into the top 7 cm, overall germination was 77% with 23% of the planted seeds surviving for 10 weeks. Where sludge was incorporated in the surface 7 cm of the tailings germination was 69%; however, survival was only 32% of total seeds planted. The Secale and Agropyron showed major advantages over the legumes. In all treatments except sludge at the 7 cm depth, practically all plant roots were in the upper 7 cm containing a mixed sludge. Where the sludge layer was at 7 cm, roots grew down to within 5 cm of the bottom of the tailings.

Pelletizing the tailings to contain 6.6% sludge and 1% of the chemical binder Coherex resulted in 68% germination and 54% survival. This study illustrates the advantage of sludge addition to the tailings, particularly when pelletized.

On strip mined land in Sulton County, Illinois reclaimed with sewage sludge from Chicago, Hinesly, Jones and Sosewitz (1972) reported that successful crops included Vicia cracca, Medicago sativa, Trifolium pratense, Melilotus sp., and Lotus corniculatus. Annuals like Zea mais, Glycine max or Avena sativa did poorly even with nitrogen fertilization; however, after four years of cropping to Medicago, Zea grew as well on reclaimed strip mine spoil as on similarly-textured undisturbed soils. The discrepancy may be due to increased soil percolation rates and moisture capacity which developed over time. Also in southern Illinois, Lejcher (1972) reported a direct relationship between vegetative cover of Festuca arundinacea or Eragrostis curvula and sludge application rates from 0 to 303.7 dry t/ha. Hendricks (1971) in Illinois reported Festuca and Eragrostis response to liquid sludge applied at rates up to 271 dry t/ha. Both species' root systems grew only in the unincorporated sludge, failing to penetrate the acid spoil with a pH of 3.0.

In lysimeters 9.8 x 1.2 x 1.2 m deep, Pennsylvania mine spoil was treated with different sludge and effluent rates to test various plant species' performance. Dickerson (1971) used acid spoil and applied 5 cm of effluent plus 5 cm of sludge, or 5 cm of sludge alone. The 5 cm of effluent loading gave the highest tree survival rate (Table 19.45). Grasses and legumes attained greatest cover with 5 cm effluent plus 5 cm sludge application (Table 19.45).

In a study similar to Dickerson (1971), Sopper and Kardos (1972) found that the highest tree survival occurred with 2.5 cm/wk sludge plus effluent treatment. One hundred percent mortality occurred on the unamended plots. Robinia pseudoacacia had the highest survival rate among the tree species. Edgerton and Sopper (1974) tested eight grasses and eight legumes for survival and preformance in lysimeters similar to those previously discussed (Dickerson 1971). The species best suited for spoil stabilization and erosion control were: Eragrostis curvula, Panicum sp., Phalaris arundinacea, Melilotus spp., Robinia hispida, Medicago sativa cv. Iroquois, Lespedeza cuneata. Best

Table 19.45. Tree survival and forage plant ground cover on acid bituminous coal mine spoil amended with sewage sludge and effluent in Pennsylvania.

		Amendment			
	Control	5 E	2.5 + 2.5	5 + 5	5S[a]
% survival					
Japanese Larch	0	2.5	0	0	0
White Spruce	0	40	10	7.5	0
Norway Spruce	0	35	2.5	2.5	2.5
White Pine	0	62.5	20	12.5	0
European Alder	0	37.5	37.5	27.5	2.5
Hydrid Poplar	0	10	2.5	10	10
Black Locust	0	65	82.5	85	67.5
% groundcover					
Orchard grass	ND[b]	28	80	100	57
Tall Fescue	ND	5	63	91	40
Birds foot Tree foil	ND	3	39	56	5
Crown Vetch	ND	2	26	58	2

Source: Adapted from Dickerson (1971).

[a] 5E : 5 cm/wk effluent
2.5 + 2.5 : 2.5 cm/wk effluent + 2.5 cm/wk sludge
5 + 5 : 5 cm/wk effluent + 5 cm/wk sludge
5S : 5 cm/wk sludge.

[b] ND = No data

production occurred with 5 cm/wk effluent plus 5 cm/wk sludge application.

In a plot experiment (Sopper, Kardos and Edgerton 1976) 10 tree species, five grass species, and five legume species were grown on burned mine refuse banks, with heat dried sludge applied at 0 to 148 t/ha dry equivalent. Treatments included irrigation with 5 cm/wk effluent or water or no irrigation.

Survival was inversely related to quantity of sludge applied (Table 19.46). Hardwood survival exceeded that for conifers. Grass and legume aerial cover was less on the unirrigated control and greater on the no-sludge and lower sludge treatment than on the highest sludge treatments.

These results contradict the lysimeter studies where survival and cover were directly proportional to sludge quantity applied. Possible explanations for an inverse relationship between survival and sludge application rate included resistance of the heat dried sludge to wetting which would tend to have a drying effect on the surface layers. Also, salt injury may have resulted from the large applications of sludge. Very dry weather during the study made salt injury a distinct possibility. Similar results and hypotheses have been reported by Kerr, Sopper and Edgerton (1979) who studied amendment of burned anthracite spoil with a combination of treated sewage effluent and domestic sewage. Surprisingly, plant survival was inversely related to sludge application rate. This was attributed to the fluffy, water repellant sludge crust which formed on the spoil surface causing plant moisture deficits. Salt toxicity at high sludge application rates may also be a problem. Conversely, tree height growth was directly related to sludge application rate. This was attributed to enhanced nutrient status.

19.5.2 Crop Performance

Agricultural and forested lands occupy a large portion of the earth's land mass. This vegetation helps minimize erosion and pollution, therefore, aspects of land management, particularly for drastically disturbed lands, must include a favourable environment for

Table 19.46. Tree seedling survival and grass and legume aerial cover on burned anthracite spoil in Pennsylvania.

Species	Sludge Application Rates - t/ha												Overall Species Mean[a] %
	0			60			36			148			
	C %	W %	E %	C %	W %	E %	C %	W %	E %	C %	W %	E %	
Trees:													
Black Locust	56	100	95	96	100	96	91	95	100	73	95	96	93.9 a
Black Walnut	91	96	100	93	100	92	82	96	90	56	87	83	88.8 a
European Alder	100	97	100	80	79	96	44	86	76	22	63	46	76.1 b
Hybrid Poplar	60	92	90	96	82	96	58	78	90	29	58	58	70.6 bc
White Spruce	93	97	100	96	92	96	22	86	76	11	53	67	70.5 bc
White Pine	96	100	100	82	61	92	49	68	90	9	18	42	68.0 bc
Austrian Pine	84	82	81	96	80	75	51	96	71	11	47	67	63.4 cd
Virginia Pine	78	96	90	33	69	96	22	73	67	0	27	33	57.0 d
Red Pine	91	86	95	60	78	92	33	96	52	2	13	25	56.8 d
Japanese Larch	87	69	88	22	58	58	13	58	36	0	4	16	41.9 e
Mean	87.6	91.3	93.3	83.4	79.9	88.5	46.5	75.0	74.8	21.3	48.5	53.3	
Overall Irrigation Mean[b]	84.7a	73.2b	77.6a										
Overall Sludge Mean[b]		80.8 a			77.7 b			65.4 c			40.2 d		
Grasses:													
Blackwell Switchgrass	10	13	18	2	5	9	0	7	2	2	5	3	6.3 a
Smooth Brome	7	48	60	3	57	52	4	8	10	4	5	5	21.8 b
Reed Canarygrass	37	63	82	57	37	98	53	92	88	50	95	98	75.8 c
Orchardgrass	52	88	78	60	100	100	45	97	52	42	52	100	78.8 c
Tall Fescue	65	73	72	62	98	98	57	82	80	35	80	88	74.4 c
Average	34.2	57.0	62.0	36.8	71.4	71.4	31.8	57.2	46.4	26.6	57.4	58.8	
Legumes:													
Bristly Locust	58	38	28	17	68	53	20	18	20	7	68	15	37.9 a
Iroquois Alfalfa	38	92	93	25	95	93	12	65	47	8	78	55	57.8 b
Ladino Clover	48	97	97	27	97	100	19	78	80	8	75	60	65.5 c
Panogift Crownvetch	18	83	52	30	87	78	40	75	60	23	83	60	61.5 bc
Birdsfoot Trefoil	42	97	100	37	100	98	35	82	67	3	65	78	66.8 c
Average	40.8	81.4	80.4	27.2	85.4	84.4	25.2	63.6	54.8	11.0	73.2	53.6	
Overall Irrigation Mean[b]	28.4a	68.2b	67.0b										
Overal Sludge Mean[b]		68.7 a			63.1 a			48.2 b			46.7 b		

Source: Sopper, Kardos and Edgerton (1976)

C = Control, W = Water, E = Effluent

[a] Overall means followed by the same letter are not significantly different at the .05 level of significance.

[b] Overall means followed by the same letter are not significantly different at the .01 level of significance.

plant growth. Improvement of soil quality facilitates sustaining vegetation. Thus, a prime consideration in land application of sewage and waste materials to drastically disturbed land is the effect on plant growth.

Halderson and Zenz (1978) concluded that crop yields are generally as great with sludge amendment as from commercial fertilization. Problems with sewage effluent or sludge amendment may include temporary inhibition of seed germination if freshly digested sludge is applied close to planting time. Salt accumulation in topsoil, particularly in arid regions, is also a potential problem.

Sutton and Vimmerstedt (1973) reported for an acid mine spoil in Ohio that sludge amendment of 659 t/ha on grasses produced 4708 kg/ha of dry matter. Yield was considerably less where no sludge and 195 t/ha limestone and 609.8 kg/ha 6-24-12 fertilizer were applied. Little growth was obtained where only 12.0 t/ha limestone and 487.6 kg/ha fertilizer were applied.

Plant growth responses to sludge and lime application were also reported by John and Van Laerhoven (1976) (Table 19.47). Lactuca sp. and Beta vulgaris were grown on silt loam soil, limed, or not limed and treated with Milorganite or air-dried primary sludge from Vancouver, British Columbia.

Lactuca yields were optimum at the 5 to 10 g/kg sludge level and were greater on the limed than on the unlimed soil. Beta root yields were enhanced where Milorganite was applied to limed and unlimed soil at the 10 or 25 g/kg sludge level.

Hortenstine and Rothwell (1972) applied municipal compost to phosphate mine tailings in Florida with or without commercial 10-4.4-8.3 fertilizer at 1 t/ha. Mineral fertilizer plus compost gave markedly increased yields of Sorghum vulgare seed heads and Avena sativa forage than did fertilizer alone (Table 19.48).

In summarizing several sludge application experiments near Chicago, Lynman, Sosewitz and Hinesley (1972) reported substantial Zea and Sorghum yield increases to digested sludge application (Tables 19.48 and 19.49).

Table 19.47. Dry weights of lettuce leaves, beet tops, and beet tubers harvest after six weeks exposure to treatment in British Columbia.

Treatment	g/kg	g, dry weight		Mean
		Unlimed	Limed	
Control	0	8.2	7.7	8.0 b
Iona sludge	5	9.5	9.6	9.5 bc
	10	10.1	12.3	11.2 c
	25	9.0	9.6	9.3 bc
	100	8.4	10.6	9.5 bc
Milorganite	5	9.2	11.9	10.5 c
	10	13.0	14.5	13.8 d
	25	4.7	10.3	7.5 b
	100	1.9	0.9	1.4 a
Mean		8.2 e	9.7 f	
Control	0	3.0 abc	3.2 abc	
Iona sludge	5	2.7 ab	3.2 abc	
	10	2.4 a	2.9 abc	
	25	2.9 ab	3.0 abc	
	100	2.6 ab	2.9 ab	
Milorganite	5	4.4 cd	3.6 abc	
	10	5.3 d	4.1 bcd	
	25	9.8 e	9.0 e	
	100	2.9 abc	5.4 d	
Control	0	1.3	1.4	1.3 ab
Iona sludge	5	1.0	1.6	1.3 ab
	10	0.6	1.0	0.8 a
	25	1.0	0.9	1.0 ab
	100	0.7	1.2	1.0 ab
Milorganite	5	1.5	1.6	1.5 bc
	10	2.0	2.0	2.0 c
	25	4.5	3.3	3.9 d
	100	0.5	0.9	0.7 a

Source: Reproduced from John and Van Laerhoven (1976), Journal of Environmental Quality, Volume 5, 1976, pages 246-251 by permission of the American Society of Agronomy, Crop Science Society of America, Soil Science Society of America.

Note: When means associated with a sludge, lime, or sludge x lime effect are followed by a common letter, they did not differ significantly at the 5% level.

Table 19.48. Corn yields and digested solids application on Blount silt loam on northeast Agronomy Research Center, Illinois 1968 to 1970.

Application rate (cm/week)	Average Corn Yields kg/ha		
	1968	1969	1970
0	4160	9000	5540
0.635	6060	9390	7500
1.27	7180	9460	7640
2.54	7040	9480	8640

Source: Lynam, Sosewitz and Hinesley (1972). Reprinted with permission from Lynam, B.T., B. Sosewitz and T.D. Hinesley. 1972. Liquid fertilizer to reclaim land and produce crops. Water Research 6(4-5): 545-549. Copyright 1972. Pergamon Press, Ltd.

Table 19.49. Oven dry (70°C) weights of sorghum seedheads and oat forage grown in tailings sand in Florida.

Material Applied t/ha			Sorghum seedheads kg/ha		Oat Forage kg/ha	
Compost	Fertilizer		1968	1969	1968	1969
0	1		138	298	998	2144
35	1		234	422	1295	3191
70	1		257	618	1292	3860
35	0		4	72	0	858
70	0		13	206	0	1405
	LSD	5%	59	56	179	652
		1%	83	83	257	852

Source: Reproduced from Hortenstine and Rothwell (1972), Journal of Environmental Quality, Volume 1, 1972, pages 415 - 418 by permission of the American Society of Agronomy, Crop Science Society of America, Soil Science Society of America.

McMillan and Carlson (1975) summarized pilot and full scale projects to assess the suitability of land application of Chicago sewage waste sludge. In a large-scale study, Zea mais yields were monitored on a 4047 ha strip mined for coal and purchased by the Sanitary District for sludge application.

Graveland (1973), Graveland and Terakita (1973), and Milne and Graveland (1972) reported application of air-dried digested sewage sludge to southern Alberta soils or subsoils in in vitro studies, with Hordeum vulgare and Phaseolus sp. Common to these studies, plant production increased substantially with heavy rates of sludge application particularly after repeated cropping. Figure 19.4, for example shows Hordeum grain yield response to sludge applied to Lethbridge loam, an Orthic Dark Brown Chernozem developed in alluvial lacustrine parent material.

Graveland and Terakita (1973) mixed air-dried activated sludge with an infertile subsoil. As sludge application increased from 0 to 30% in vitro Phaseolus yield increasesd 2½ times.

Milne and Graveland (1972) applied air-dried digested sewage sludge at 34, 67, and 101 t/ha to the Orthic Chernozemic soils: (1) Cavendish sandy loam, (2) Lethbridge loam, and (3) Coaldale clay loam. Nitrogen and phosphorus were added at the rate of 56 kg/ha and additional fertilizer treatments were applied at the same rate for Hordeum but without sludge addition (Figure 19.5). On all soils the initial crop yields increased with increasing sludge rates up to 101 t/ha with greatest increase in the Coaldale soil. No response was obtained to sludge application by the second crop, suggesting that sludge applied nutrients had been used by the first crop or by micro-organisms in decomposition. Nitrogen appeared to be the main limiting factor with sludge amendment.

19.5.3 Crop Quality

Halderson and Zenz (1978) pointed out that in the land application of sewage effluent and sludge for growing crops for human consumption the chief concern is the public health problem associated

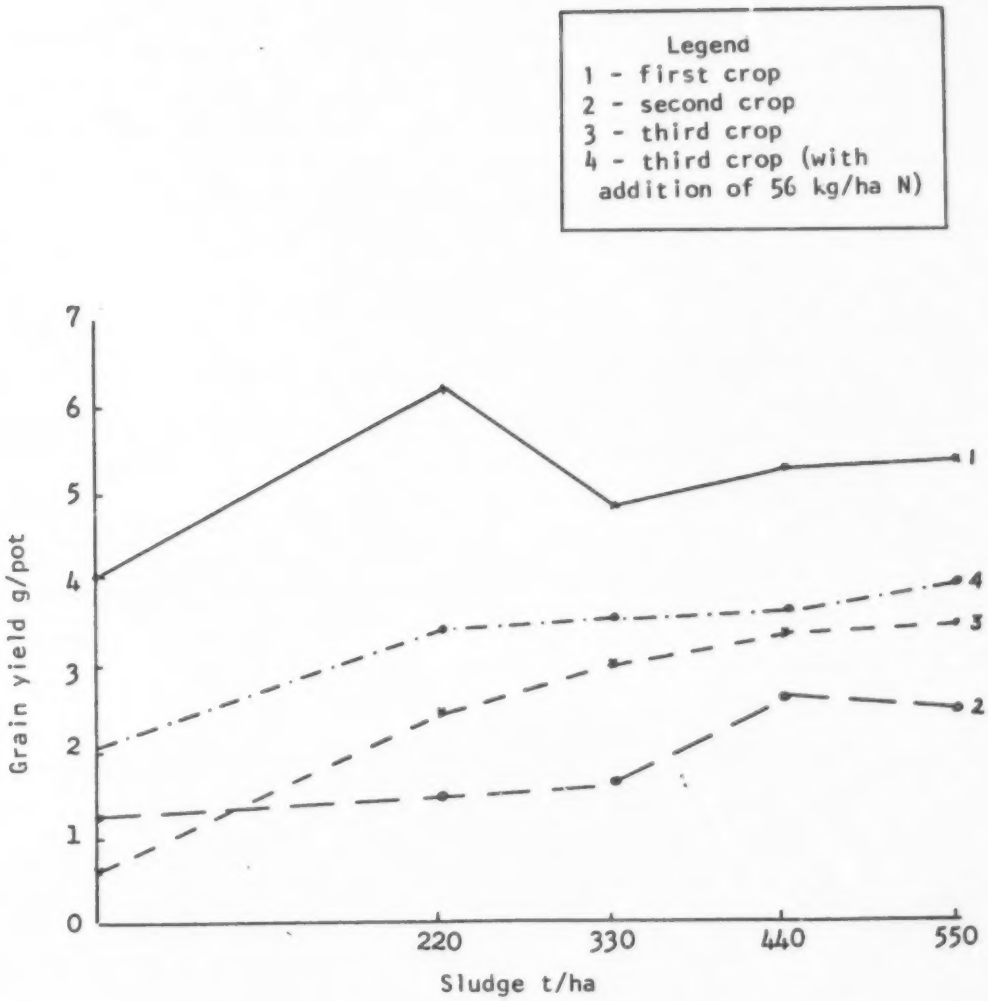

Figure 19.4 Barley yields of three consecutive crops at five levels of sludge applied to a Lethbridge loam.

Source: Graveland (1973)

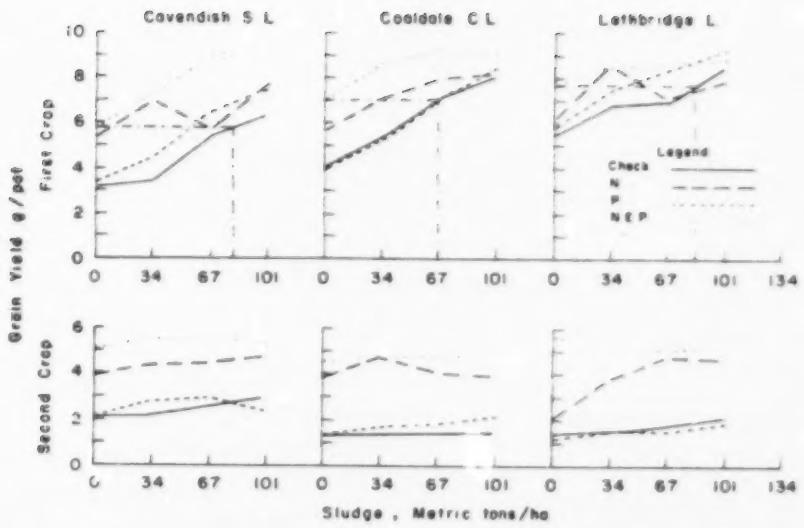

Figure 19.5. Barley yield with three levels of sludge in combination with N and P (first and second crops), applied to various soils near Lethbridge, Alberta.

Source: Milne and Graveland (1972)

with the heavy mineral uptake. Studies at the University of Illinois indicated that cadmium content of Zea mais grain was increased by greater applications of sludge but not by increasing the years of sludge application. The data indicated that metal accumulation is not a significant hazard when application amounts do not exceed plant nitrogen requirements. Soil pH should be maintained at 6.5 or above. Crops should be those that do not accumulate excess amounts of heavy metals and application rates of dry sludge should not exceed 56 t/ha if crops are to be grown in the same year. If applications are higher, a fallow year is advisable or the crop product should be analyzed before marketing.

Sopper, Kardos and Edgerton (1974) and Sopper, Kardos and DiLissio (1975) analysed grass and legume tissue grown on a very non-productive mine spoil irrigated weekly with 5 cm of sewage sludge, 2.5 cm of effluent plus 2.5 cm of sludge, or 5 cm of effluent plus 5 cm of sludge. The results of both studies were similar (Table 19.50).

Legumes tended to be higher in N, K, Ca, and Mg but lower in P than the grasses. Nitrogen and P were increased by increased sludge and effluent applications. Despite relatively high concentrations of Al, Mn, Fe, and Cu there were no symptoms of micronutrient toxicity. Boron remained below the reportedly toxic level. Edgerton and Sopper (1974) also indicated that the relationship between production and metals concentration may differ between grasses and legumes. Grasses achieving the greatest dry matter production had the lowest heavy metals concentration in the above-ground tissues, whereas legumes having high yields often had high metals concentration.

The effects of adding sludge at 50% moisture to two sandy loam soils and a clay soil at 8% by weight on the metals concentration in Lactuca sp. and Lycopersicon esculentum tops were reported by Gaynor and Halstead (1975). They found metals concentrations were increased by sludge application.

Table 19.50. Chemical composition of grasses and legumes on sludge and effluent amended strip mine spoil in Pennsylvania.

	Grass			Legume		
	2E[a]	1E+1S	2E+2S	2E	1E+1S	2E+2S
% of Dry Weight						
Nitrogen	2.51	3.39	3.74	4.13	4.49	4.04
Phosphorus	0.33	0.41	0.55	0.26	0.36	0.37
Potassium	2.01	1.22	1.54	2.13	1.48	1.83
Calcium	0.33	0.40	0.57	1.27	0.72	0.98
Magnesium	0.31	0.26	0.33	0.57	0.46	0.45
ppm						
Manganese	214	154	224	193	284	160
Iron	142	431	409	227	345	370
Copper	16	35	79	13	24	28
Boron	13	9	12	47	36	38
Aluminum	76	364	386	74	204	217
Zinc	58	111	152	56	90	84
Sodium	214	545	622	500	514	592

Source: Adapted from Sopper, Kardos and DiLissio (1975).

[a] 2E = 5 cm/7 d effluent
1E + 1S = 2.5 cm/7 d effluent plus 2.5 cm/7 d sludge
2E + 2S = 5 cm/7 d effluent plus 5 cm/7 d sludge

19.5.4 Survival of Micro-organisms

The possible contamination of food materials or surface and groundwaters with disease or parasitic organisms from sewage sludge or effluent applied to crop land is a prevalent concern. The early practice of land disposal of sewage as a primary treatment controlled cholera epidemics at least to some extent, indicating that pathogenic organisms were destroyed by this means of disposal.

Sewage plant treatment destroys a majority of the human pathogens that raw sewage contains. Application of sewage effluents and sludges to soil further reduces numbers of bacteria, viruses or parasite propagules through drying, exposure to sunlight, chemical action or absorption.

Three papers referred to the survival of sewage-born microflora, specifically coliforms. All were reports from Illinois. Lejcher (1972) applied anaerobically digested sludge to plots at 0, 78, 178, and 304 dry t/ha and reported that coliform analyses for total and fecal coliforms in the runoff showed complete dieoff. Lysimeter experiments by Lynman, Sosewitz and Hinesly (1972) showed that digested sludge increased NO_3 levels in run-off and soil leachate but without increase in fecal coliforms. The rapid disappearance of fecal coliforms on the soil surface after application of freshly digested sludge is shown in Table 19.51.

McMillan and Carlson (1975) reported that fecal coliforms in impounded "liquid fertilizer" reduced from 40 000 to 200/mL in 32 days and in the supernatant, from 300 to 0/mL in the same time. They also found a 99.9% dieoff in fecal coliforms within 30 days of working sewage into the soil.

Lue-Hing, Sedita and Rao (1979) studied pathogenic soil microfauna including viruses and bacteria in sludge amended spoils at the PALZO strip mine in southern Illinois. The sewage sludge was from Chicago (MDGC). Sludge amendment of local agricultural soils had little effect on total bacterial population levels (Table 19.52).

Also in the PALZO tract in Illinois, Sundberg, Borders and Albright (1979) studied changes in microfungal population in sludge

Table 19.51. Fecal coliform survival in digested solids cake covering a soil surface in Illinois.

Days after application of freshly digested solids	No. of fecal coliforms per g digested solids cake (dry weight)
1	3 680 000
2	655 000
3	590 000
5	45 000
7	30 000
12	700

Source: Lynam, Sosewitz, and Hinesly (1972). Reprinted with permission from Lynam, B.T., B. Sosewitz and T.D. Hinesley. 1972. Liquid fertilizer to reclaim land and produce crops. Water Research 6(4-5): 545-549. Copyright 1972. Pergamon Press, Ltd.

Table 19.52. Microbial populations in control and test fields, 1975 and 1976 in southern Illinois (geometric mean counts per dry gram of soil).

	Test Fields				
	3	9	20	21	Field 6
Sludge applied[a] [(t/acre) (t/ha)]	77.9(174)	45.8(103)	50.4(113)	56.1(126)	None
Total coliform	4.9×10^3	1.7×10^4	8.0×10^3	1.2×10^3	9.0×10^2
Fecal coliform	4.3×10^2	6.2×10^2	7.4×10^1	7.2×10^0	3.9×10^1
Fecal streptococci	6.7×10^3	4.3×10^4	1.8×10^3	1.7×10^2	2.2×10^3
Total plate count	1.3×10^9	1.4×10^9	3.3×10^9	4.4×10^8	3.2×10^8
Pseudomonas aeruginosa	2.7×10^4	2.5×10^3	1.8×10^4	2.4×10^4	4.3×10^3
Staphylococcus aureus	NR[b]	NR	NR	NR	NR
Salmonella	NR	NR	NR	NR	NR

Source: Lue-Hing et al. (1977).
[a] Sludge applied through 1976 (cumulative).
[b] NR. not recovered.

amended spoils. Fungal population, density composition, and species frequency were studied in sludge amended and unamended spoil, and in undisturbed soils. The acidic organic deficient and typically dry spoil had very low microfungal population densities compared to undisturbed soils (for example, about two orders of magnitude less, Figure 19.6). Incorporation of sewage at 560 dry t/a increased spoil fungal populations by about an order of magnitude.

Soil column studies on sludge amendment showed viral transport was limited to the surface several centimetres. Studies on the level of viruses and bacteria in surface runoff also failed to detect elevated levels related to sewage farming. Studies of well water showed similar low pathogenic bacteria and viral levels. Exceptions were attributed to contamination with surface waters or experimental error (Table 19.53).

Studies were also done on the aerial transport of organisms due to spraying of lagoonal sludge. Occasional elevated levels were detected within 500 m of the source (Table 19.54) although it was hypothesized this was probably due to natural background levels and contamination.

19.6 SUMMARY

Sewage sludge and effluent is usually very rich in nutrients and is thus considered an excellent source of nutrients and organic matter in place of more conventional amendments. Sewage is often, however, also rich in heavy metals, bacteria, and other pathogens and is also an odour source. Sewage varies considerably in its constituents and should be analyzed carefully before decisions are made as to use.

The economics of sewage application to mine spoils depends largely upon access to large urban centers, as transportation frequently represents greater than 50% of costs. Other costs such as site preparation to prevent ponding, runoff, and groundwater contamination plus on site storage and special handling equipment may be significant. Fertilizers must sometimes be added to correct nutrient imbalances.

Sewage amendment may not be practical on all sites. Low organic soils, for instance, may react too slowly to assimilate sludge.

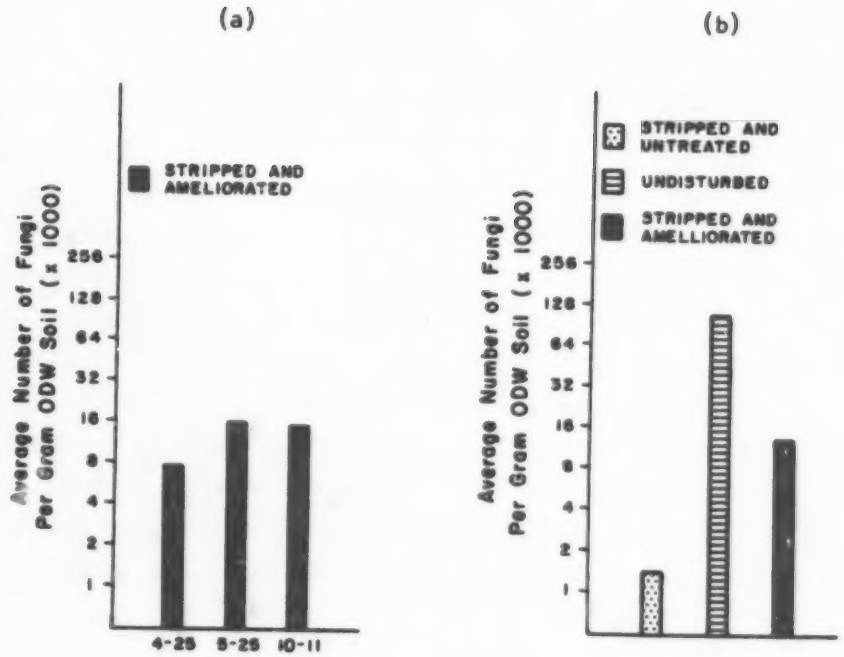

Figure 19.6. (a) Numbers of saprolic fungal colonies per gram of oven-dried stripped and sewage sludge-ameliorated soil; (b) Average numbers of saprolic fungal colonies per gram of oven-dried stripped and untreated, stripped and ameliorated, and undisturbed soils.

Source: Sundberg, Borders and Allbright (1979) Reproduced by permission of Penn State Press.

Table 19.53. Virological and bacteriological data from the Fulton County, Illinois well water analysis.

Sample Source	Date	Sample Volume (L)	Viruses/L (Based upon Fraction Confirmed)	Bacteria/L		
				Total Coliform	Fecal Coliform	Fecal Streptococci
W-14	10/30/74	40	0	NA[a]	NA	NA
W-14	11/20/75	20	0	NA	NA	NA
W-14	12/18/75	30	0	0	0	0
W-6	12/18/75	40	0	NA	NA	NA
W-14	1/6/76	20	0	1.0×10^2	0	0
W-12	1/22/76	20	0	8.0×10^2	0	0
W-12	2/9/76	16	0	0	0	0
W-12	3/16/76	20	0	0	0	0
W-14	3/18/76	20	0	0	0	0
W-12	3/30/76	39.6	0	0	0	0
W-12	4/13/76	40.6	0	NA	0	NA
W-6	4/23/76	39.9	0	NA	0	NA
W-12	5/20/76	40.2	0	0	0	0
W-12	7/7/76	40.0	0	0	0	1.0×10^2
W-12	7/22/76	40.4	0	1.0×10^2	0	0
W-12	9/8/76	35.0	0	0	0	0
W-14	9/22/76	39.2	0	1.6×10^2	0	5.2×10^3

Source: Sundberg, Borders and Albright (1979). Reproduced by permission of Penn State Press.

[a] NA, lab errors, data not available.

Table 19.54. Concentrations of animal virus, coliphage, and total bacte a detected in aerosols at MSDGC sludge irrigation site, Illinois, May, July, August, September, 1976.

Date Sampled	Distance from Source (m)	Test Conditions: Wind Speed (Miles/hr (km/hr)	Test Conditions: Relative Humidity (%)	Test Conditions: Temperature (°C)	Test Conditions: Stability Class	Test Conditions: Air Volume Sampled (m^3)	Concentration/m^3: Animal Viruses (PFU)	Concentration/m^3: Coliphage (PFU/PFU)	Concentration/m^3: Total Bacteria (CFU)	Notes
5/25	100	4.9 (7.9)	31	21.1	A-B	30	0	0	3.1×10^4	a,b
5/26	400	2.7 (4.3)	31	30.1	A	31	0	0	2.0×10^5	a
5/26	50	5.1 (8.2)	39	25.9	B-C	36	0	1.0×10^{-1}	3.8×10^4	a
5/26	75	4.7 (7.6)	73	22.5	A-B	31	0	0	1.7×10^4	a
5/26	100	4.3 (6.9)	72	22.2	A-B	23	0	0	1.3×10^5	a
5/26	Upwind control (450)	4.7 (7.6)	36	22.8	B	30	0	0	1.5×10^2	a
5/27	200	4.4 (7.1)	36	24.4	B	40	0	0	9.9×10^3	a
5/27	300	4.3 (6.9)	36	23.9	B	49	0	5.3×10^{-1}	6.4×10^4	a
5/27	250	<3.5 (5.6)	78	24.4	B	25	0	0	2.0×10^4	a
5/27	300	<3.5 (5.6)	78	24.4	B	62	0	5.5×10^{-2}	1.4×10^5	a
5/27	Upwind control[c]	<3.6 (5.8)	46	22.2	B	30	0	0	5.5×10^2	a
5/25	Sludge spray source	ND	ND	ND	ND	ND	0 PFU/l	1.3×10^3 PFU/l	8.2×10^8 CFU/l	d,e
5/26	Sludge spray source	ND	ND	ND	ND	ND	0 PFU/l	3.0×10^4 PFU/l	5.2×10^8 CFU/l	d,e
5/27	Sludge	ND	ND	ND	ND	ND	0 PFU/l	3.0×10^4 PFU/l	1.1×10^8 CFU/l	d,e
7/31	50	6.3 (10.1)	66[f]	28.9	B	37	0	0	ND	a
						0.42	ND	ND	5.3×10^2	g
7/31	200	5.6 (9.0)	57	29.4	B	160	0	0	ND	a
						1.70	ND	ND	5.8×10^3	g
7.31	300	4.3 (6.9)	87	25.0	B	31	0	0	ND	a
						0.79	ND	ND	5.2×10^2	g
7/31	Upwind control (450)	1.6 (2.6)	87	25.0	B	60	0	0	ND	a,h
						1.70	ND	ND	4.6×10^1	g
7/31	Sludge spray source	ND	ND	ND	ND	ND	0 PFU/l	0 PFU/l	2.8×10^7 CFU/l	d
8/31	200	7.4 (11.9)	47	26.7	B	127	0	3.8×10^{-2}	ND	a
						0.56	ND	ND	6.2×10^2	g
8/31	250	7.2 (11.6)	37	30.6	B	60	2.1×10^{-2}	3.8×10^{-1}	ND	a
						0.56	ND	ND	5.5×10^2	g
8/31	425	4.5 (7.2)	45	27.8	B	175	0	5.5×10^{-2}	ND	a
						0.56	ND	ND	2.2×10^3	g
8/31	450	6.0 (9.7)	41	28.3	B	53	0	5.3×10^{-4}	ND	a
						0.56	ND	ND	6.6×10^3	g
8/31	Upwind control (150)	5.0 (9.7)	38	29.4	B	127	0	3.9×10^{-2}	ND	a
						0.56	ND	ND	4.2×10^2	g
8/31	Sludge spray source	ND	ND	ND	ND	ND	0 PFU/l	6.5×10^4 PFU/l	2.2×10^7 CFU/l	d
9/1	50	9.6 (15.4)	69	23.3	B	10	0	2.2×10^3 PFU	ND	a
						0.53	ND	ND	1.4×10^3	g
9/1	150	3.1 (5.0)	47	26.7	A	36	0	4.7×10^2 PFU	1.7×10^5	a,c
9/1	150	7.6 (12.2)	47	28.3	B	26	1.8×10^{-1}	6.8×10^2 PFU	1.1×10^6	a,c
9/1	175	7.6 (12.2)	53	27.8	B	69	0	4.3×10^2 PFU	ND	a,c
						0.56	ND	ND	8.5×10^2	g
9/1	400	3.1 (5.0)	47	26.7	A	66	0	1.8×10^{-1} PFU	6.8×10^5	a,c
9/1	Sludge spray source	ND	ND	ND	ND	ND	0 PFU/l	7.0×10^4 PFU/l	2.8×10^9 CFU/l	d
9/2	250	4.9 (7.9)	NA	27.8	A-B	200	8.7×10^{-3}	6.4×10^1 PFU	ND	a,c
						0.56	ND	ND	4.9×10^2	g
9/2	Upwind control (175)	2.7 (4.3)	NA	25.0	A	63	4.3×10^{-2}	1.2×10^2 PFU	ND	a,c
						0.56	ND	ND	3.6×10^2	g
9/2	Sludge spray source	ND	ND	ND	ND	ND	0 PFU/l	6.0×10^4 PFU/l	1.3×10^{10} CFU/l	d

Source: Brooks et al. (1976) Reproduced by permission of Penn State Press.

a Counts from Litton high-volume sampler field. B, no positive observation.

b All stability classes based on method of Lighthart and Frisch (1976).

c Sample collected outside the MSDGC Research and Development Laboratory premises, while the sludge transportation was occurring in an adjacent field.

d 200-mL spray source concentrated for animal virus counts. For coliphage counts, NPB tubes scored positive by placing drop from tube on lawn of host cells E. coli C3000, and observing for plaque formation bacterial counts by serial dilution and spread plates on trypticase soy agar.

e Coliphage counts by direct ...ation assaying serial dilutions and soft agar overlays with host cells E. coli C3000.

f A rain precipitation was observed during the sampling period.

g Bacterial counts by Andersen sieve-stage sampler using trypticase soy agar.

h Sample was lost during processing.

Sewage contains many essential nutrients in significant quantities (e.g., Ca, K, Mg, N). Sewage may increase pH and thus decrease problems associated with heavy metals. Nitrification may also be increased by sewage application. However, this may lead to decreased soil pH or excessive leaching of nitrogen. Carbon:nitrogen ratios may be increased beyond optimum levels. On acid spoils, sewage application may increase pH and decrease leaching of metals. Heavy sludge applications may result in high nitrogen in percolates, in the form of NH_4 or NO_3, depending on soil pH. Nutrients such as P, K, and Ca generally do not increase in effluent from sewage amended acid spoils. Chlorine may increase in the leachate. Manganese may increase or decrease, depending upon spoil chemistry, though generally it decreases in leachate.

Numerous heavy metals are associated with sewage application. Ionic forms of Pb, Fe, Cd, Zn, Ni, and Cu may be present at toxic levels. Heavy metal concentrations in plants are generally not a problem when pH is greater than 6.5 and when sludge application does not exceed plant nitrogen requirements. Conversely, reduced uptake by plants may result in undesirable accumulations in the spoil.

Results of research on sewage amendments to natural soils are not necessarily applicable to spoils and should be interpreted with caution.

Amendment with sewage generally increases infiltration and water-holding capacity of spoils, reducing runoff and erosion. Surface and subsurface temperatures are apparently not significantly altered.

Sewage amendment generally enhances crop establishment on spoils. Cereal grains and grasses usually respond very well and generally better than legumes. Some annual crops such as Glycine max and Zea mais may perform poorly in the first few years until the physical characteristics of the spoil are improved.

Trees established well with sewage amendment of spoils, with hardwoods performing better than conifers.

Response of vegetation to rates of application is variable. Often there is a direct relationship between performance and rate, but

not always. Inverse relationships may be due to crusting, hydrophobic reactions, or toxicities of some sludges applied at high levels.

Yield response of numerous crops to sewage amendments on a variety of spoils, tailings, and natural spoils has been quite positive and often better than from comparable fertilizer treatments. However, continued periodic applications may be necessary.

Increasing sewage application rates may increase heavy metal uptake by plants. A limited application (55 dry t/ha has been suggested in Illinois) is acceptable if crops are grown in the same year. If application rates are higher a fallow year may be necessary. Also, where rates are high, crops should be analyzed. Soil pH should be maintained at greater than or equal to 6.5. Crop selection should consider tendencies to accumulate heavy metals. The dilution effect (yield/concentration) is apparently more evident in grasses than in legumes; in the latter, concentrations of metals often increase with yield.

Land application of sewage destroys many pathogens not killed by primary treatment. Generally, a large dieoff occurs within 30 days. Most research has not revealed major problems but results are inconclusive and more research is needed.

Much of the research on sewage amendment has been carried out on acid spoils. Considerable research has been done on natural soils in Alberta but more research is needed on spoil materials.

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Volume

2

REPORT #
RRTAC 84-1

Land Surface Reclamation: A Review Of The International Literature Volume II

Heritage Fund

Alberta
LAND CONSERVATION AND
RECLAMATION COUNCIL
Reclamation Research
Technical Advisory Committee
ENVIRONMENT
Research Management Division

ALBERTA'S RECLAMATION RESEARCH PROGRAM

The regulation of surface disturbances in Alberta is the responsibility of the Land Conservation and Reclamation Council. The Council executive consists of a chairman from the Department of the Environment and two deputy chairmen from the Department of Energy and Natural Resources. Among other functions, the Council oversees programs for reclamation of abandoned disturbances and reclamation research. The reclamation research program was established to provide answers to the many practical questions which arise in reclamation. Funds for implementing both the operational and research programs are drawn from Alberta's Heritage Savings Trust Fund.

To assist in technical matters related to the development and administration of the research program the Council appointed the Reclamation Research Technical Advisory Committee (RRTAC). The Committee first met in March, 1978 and consists of eight members representing the Alberta Departments of Agriculture, Energy and Natural Resources, Environment and the Alberta Research Council. The Committee meets regularly to update research priorities, review solicited and unsolicited research proposals, arrange workshops and otherwise act as a referral and coordinating body for Reclamation Research.

Additional information on the Reclamation Research Program may be obtained by contacting:

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This Report may be cited as:

Sims, H.P., Powter, C.B., and Campbell, J.A.1984. Land Surface Reclamation: A review of the International Literature. Alberta Land Conservation and Reclamation Council Report #RRTAC 84-1. 2 Vols. 1549 pp.

Additional Copies may be obtained from:

Publication Services
Queen's Printer
11510 Kingsway Avenue
EDMONTON, Alberta
T5G 2Y5

LAND SURFACE RECLAMATION:

A REVIEW OF THE INTERNATIONAL LITERATURE

REPORT #RRTAC 84-1

H.P. Sims
C.B. Powter
J.A. Campbell

Prepared for the Alberta Land Surface Conservation
and Reclamation Council

by

Alberta Environment
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SECTION VII

USE OF AGRONOMIC AND

INTRODUCED SPECIES IN RECLAMATION

Revegetation using agronomic grasses and legumes in Alberta has been concentrated in three main areas: (1) the oil sands near Fort McMurray; (2) the Swan Hills area; and (3) the foothills/mountain region with major studies at Blairmore, Luscar, and Grande Cache. Additional studies relevant to the oil sands were carried out on sand dune areas near Lesser Slave Lake. Very little similar research has been carried out in the plains region of Alberta. Considerable work has been done in that region with cereal crops and some forage crops but either at the operational level or as field trials with almost no publication of quantitative results.

Research from other areas of North America and elsewhere is also cited, as many species relevant to Alberta have been used in those areas and information is in many instances applicable to Alberta.

While considerable research has been carried out on the use of introduced (exotic, ornamental) shrubs and trees for reclamation purposes, its relevance to Alberta is far more restricted than for grasses and legumes. This is primarily because the woody species are generally less ubiquitous than the herbaceous species, less tolerant of harsh conditions, and of course have a far more restricted regenerative capacity.

The majority of work with shrubs and trees has been done in the eastern United States and most of the species used will not tolerate Alberta's much harsher conditions. Probably the area of second greatest effort is in the semi-arid and arid regions of the southwestern United States and, again, these species have only limited application in Alberta. In the plains regions, where strip mining of coal has resulted in major developments of reclamation practices the emphasis has of course been placed on grasses and legumes for agricultural purposes.

The research that has been carried out using trees and shrubs has been less sophisticated than that done with grasses and legumes. There are a number of possible reasons for this. Probably one is that much reclamation research has been designed by agriculturalists. A

second reason may be the ease of propagating and handling stock, and a third the relative paucity of information on trees and shrubs.

It is quite difficult to apply results of research with trees and shrubs on a regional basis. The species that appear to be most useful for Alberta probably have applicability firstly in the Plains region, and secondly in the North-east (Oil Sands) region.

20. USE OF AGRONOMIC GRASSES AND LEGUMES IN REVEGETATION OF THE NORTH-EAST (OIL SANDS) REGION

Work in the oil sands has concentrated primarily on revegetation of the tailings dikes for erosion control, although work has also been done on overburden waste dumps. Summarization of the oil sands studies has been complicated by a number of factors. Studies were usually very complex (species comparisons were combined with site preparation and amendment treatments), sometimes poorly designed, and not comparable in terms of methodology and design.

One early study on tailings dikes (Berry 1970) attempted to establish grasses and legumes on a 15% slope at Fort McMurray. The pH of the sand ranged from 7.0 to 9.0; essential nutrients (N,P,K) were not present. Bromus inermis (11.2 kg/ha), Agropyron cristatum (8.9 kg/ha) and Festuca rubra and Melilotus alba at 5.6 kg/ha, were broadcast seeded on plots onto which 10 cm of black clay plus 8 to 20 cm of muskeg had been pre-mixed and spread. Bare sand and plots containing muskeg only were also studied. Plots were fertilized and seeded, harrowed with a drag harrow, and fertilized again for a total of 673 to 897 kg/ha of 8-24-24. Plots were irrigated by tank truck using 30 283 L of water on 0.5 ha. An irrigation system was set up and the plots fertilized again with 112 kg/ha of 34-0-0 and 112 kg/ha of 8-24-24. Later assessment of this same study concluded that irrigation was necessary only to provide sufficiently fast seed germination and plant growth on sand to keep ahead of wind erosion (Klym and Berry 1975; Berry and Klym 1974). Legume success was 5% or less and soil pH was not reduced. Festuca rubra dominated the grass cover. Black clay used in the study had a detrimental effect on germination and growth, apparently because of the presence of lean tar sand.

Operational trials developed from field plots were performed on a 14.2 ha block (Klym and Berry 1975; Berry and Klym 1974). Muskeg was dumped at the crest of a slope, spread and levelled with a tractor pad pulled by a Nodwell and mixed with a Howard rotovator. Seed at a rate of 34 kg/ha (Bromus inermis 33%, Agropyron cristatum 24%, Festuca rubra 15%, Melilotus alba 14% and Trifolium hybridum 14%; by weight)

was hydroseeded on a 22° slope together with 448 kg/ha of 8-24-24 fertilizer and 561 L/ha of soil oil SSC. An irrigation system was installed on the area. A complete fertilizer (224 kg/ha) was provided in spring and fall. The trial found that packing of the seed-bed by the Brillion grass seeder improved germination and plant growth. While success on irrigated areas was very good, plants on non-irrigated areas provided sufficient growth to stop wind erosion and reduce water erosion.

Lesko (1974a) carried out trials on tailings sand on the Great Canadian Oil Sands (Suncor) dike (3:1 slope; SE facing). Eleven seed mixtures (Table 20.1) were tested on three treatments: (1) grading followed by contour trenching 7.5 cm deep at 15 cm spacing; (2) grading followed by packing with a crawler tractor after seeding; and (3) grading only. Species were hydroseeded in spring followed by a hydromulch containing wood-fibre, curasol AH adhesive and fertilizer (32.5 g/m^2 each of 10-30-10 and organic fertilizer and 15 g/m^2 of 46-0-0). Additional fertilizer (450 kg/ha of 15-15-15) was applied the following spring.

The most successful grass species were Agropyron cristatum, A. trichophorum, A. riparium, Agrostis alba, Bromus inermis, Dactylis glomerata and Phleum pratense. Success of forbs and woody species was negligible. Grasses did not establish well (16% of germination capacity maximum; average 5%).

Erosion was a major problem on all treatments and reduced success considerably.

Sites prepared by GCOS (Berry and Klym 1974; Berry 1970) were fertilized with various mixes of NPKS and lime (Table 20.2; Takyi et al. 1977) including regular GCOS rates. The relative increases of the grasses is misleading because of the initial composition of the stand (90% Festuca rubra, Table 20.3). However, it is quite obvious that F. rubra dominated and increased at least 150% with all treatments. The increase of Bromus inermis was substantial only under treatment T_{3A}. These results are interesting as Bromus is considered to be very responsive to fertilizer.

Table 20.1. Seed mixture used in revegetation tests on the Suncor dike, Fort McMurray, Alberta.

Seed Mixtures		
Mix 1	Mix 2	Mix 3
Agropyron cristatum *Amelanchier alnifolia* *Aster conspicuus*	*Agropyron latiglume* *Prunus virginiana* *Lonicera tatarica*	*Agropyron riparium* *Poa pratensis* *Rosa woodsii*
Mix 4	Mix 5	Mix 6
Pinus contorta var. *latifolia* *Agropyron trichophorum* *Caragana arborescens*	*Agrostis alba* *Medicago sativa*	*Bromus inermis* *Melilotus alba*
Mix 7	Mix 8	Mix 9
Dactylis glomerata *Vicia americana* *Cornus stolonifera*	*Picea engelmannii* *Elymus junceus* *Elaeagnus commutata*	*Festuca rubra* *Phleum pratense* *Epilobium angustifolium*
Mix 10	Mix 11	
Koleria cristata *Phacelia sericea* *Lunaria dalmatica*	*Picea glauca* *Agropyron cristatum* *Phleum pratense* *Caragana arborescens* *Epilobium angustifolium* *Lunaria dalmatica*	*Pinus contorta*, var. *latifolia* *Bromus inermis* *Rosa woodsii* *Medicago sativa* *Phacelli sericea*

Source: Lesko (1974a).

Table 20.2. Fertilizer treatments (1975) of revegetated sites on the Suncor dyke, Fort McMurray, Alberta.

Treatment

T_o = No fertilizer or lime (Nil).

T_oA = 90 kg/ha N[a] and 9.0 kg/ha S applied in August (17th).

T_1 = NPKS in June (19th). N:P:K:S = 90:22:90:9 kg/ha/y.

T_{1A} = Same as T_1 plus 90 kg/ha N and 9.0 kg/ha S applied in August (17th).

T_2 = NPKS plus lime in June (19th). Same as T_1 plus 11 t/ha of lime in the first year only.

T_{2A} = Same as T_2 plus 90 kg/ha N and 9.0 kg/ha S applied in August (17th).

T_3 = $N_2P_2K_2S_2$ in June (19th). N:P:K:S = 180:45:180:18 kg/ha every other year.

T_{3A} = Same as T_3 plus 180 kg/ha N and 18 kg/ha S applied in August (17th).

T_4 = $N_2P_2K_2S_2$ + lime on June (19th). Same as T_3 plus 11 t/ha of lime in the first year only.

T_{4A} = Same as T_4 plus 180 kg/ha N and 18 kg/ha S applied in August (17th).

T_5 = GCOS rate -- Summer application (made August 17th).

T_5[b] = GCOS 1975 fertilizer rates (kg/ha):

	Spring (June)	Summer (August)	Total
N =	15.1	26.9	42.1
P =	5.8	5.8	11.7
K =	11.2	11.2	22.4
S =	13.5	26.9	40.4

T_{5A} = Same as T_5 plus extra N added to bring total N for spring and summer applications to 90 kg/ha N (extra N was in the form of ammonium nitrate).

Source: Adapted from Takyi et al. (1977 various paging).

[a] N = Ammonium phosphate
Ammonium phosphate
P = Ammonium phosphate
K = Potassium sulphate
Potassium chloride
S = Potassium sulphate
Lime = Finely ground agricultural lime

[b] For treatment T_5:
N = Ammonium sulphate (6-24-24)
P+K = (6-24-24)
S = Ammonium sulphate

Table 20.3. Dry matter yields [a] (for entire growing season) of bromegrass and creeping red fescue as affected by fertilizer and lime treatments on a vegetated tailings pond dike, Fort McMurray, Alberta.

Treatment		Yield (t/ha)		
		Bromegrass[b]	Creeping Red Fescue	Bromegrass + C.R. Fescue
T_o	Nil	0.02	0.54	1.23
T_{oA}	Nil + NS	0.18	2.89	3.07
T_1A	NPKS + NS	0.18	4.44	4.62
T_2A	NPKS + lime + NS	0.11	5.16	5.27
T_{3A}	$N_2P_2K_2S_2 + N_2S_2$	0.76	4.33	5.09
T_{4A}	$N_2P_2K_2S_2$ + lime + N_2S_2	0.18	4.64	4.82
T_5	GCOS Rate (spring and summer)	0.18	3.18	3.36
T_5	GCOS Rate (spring and summer + N) plus N	0.11	3.63	3.74

Source: Adapted from Takyi et al. (1977)
[a] A total of two harvests on 17 Aug. 1975 and 7 Oct. 1975.
[b] Yield is average of three replicates.

In the same study (Takyi et al. 1977) several species of grass and legume species (Festuca rubra, F. saximontana, Agropyron trachycaulum, Bromus inermis, Elymus innovatus, Puccinellia ruthlaliana, Astragalus cicer, Onobrychis sp. and Medicago sativa) were sown on good agricultural soil (Malmo), lean oil sand, and heavy oil sand/Malmo soil mixed. The mixes were fertilized with a complete fertilizer plus lime and micronutrients. Comparable field conditions were simulated in the growth chamber. Yields from the first seeding were very low on the heavy oil sand mix and would not provide adequate cover but increased greatly in the second seeding and roots penetrated lumps of heavy oil sand. However, use of good agricultural soil is relatively meaningless in this area. Both seedings on the lean sand produced good results although the second crop was much better (Table 20.4).

A second study was carried out on peat, tailings sand and overburden (2:2:1 by volume), and tailings sand and peat (1:1 by volume). Plants were grown in pots under simulated field conditions in the growth chamber. Nitrogen at 22 kg/ha was added to each mix and lime and no-lime treatments imposed over that. Astragalus cicer, Onobrychis sp., Trifolium hybridum and Medicago sativa were tested. Results are indicated in Table 20.5. While nodules were present, probability of N fixation appeared low. Trifolium hybridum and Medicago outperformed the other species.

Pot experiments using several soil mix-fertilizer interactions were carried out under controlled conditions in the greenhouse (Takyi et al. 1977). Two grass legume mixtures (Agropyron trachycaulum/Onobrychis sp. and Bromus sp./Medicago sativa) were sown. Two seedings were done and results were similar for both, although yields were higher in the second seeding (about 1.5 to 2 times) except on the tailings sand with full fertility treatment; yield was very low with no treatment (Table 16.31). For some reason, yields of the two grass/legume mixes were averaged, even though they were not similar on all treatments. No analyses were done but, with the exception of production on good agricultural soil, yields were about the same on all

Table 20.4. Yields of tops and roots of the species grown on two oil sand-bearing materials as compared with yields on a good agricultural soil (Malmo), first and second seeding (grams per pot).

Species	First Seeding			Second Seeding		
	Malmo[a]	Malmo + Heavy Oil Sand	Lean Oil Sand	Malmo[a]	Malmo + Heavy Oil Sand	Lean Oil Sand
Saximontana fescue	6.38	ND[c]	4.34	6.55	1.23	0.89
Slender wheat grass	10.92	0.08	3.92	11.85	4.71	9.88
Bromegrass[b]	9.07	0.19	3.03	14.88	4.69	9.49
Alkali grass[b]	4.99	ND	0.43	8.30	0.60	7.75
Hairy wild rye	6.32	0.10	2.21	7.54	3.18	5.27
Creeping red fescue	16.64	0.51	6.34	19.28	7.23	15.46
Cicer milk vetch[b]	2.51	ND	1.91	8.93	0.13	6.42
Sainfoin[b]	5.68	0.09	1.32	11.59	0.65	5.15
Alfalfa	11.70	0.07	2.87	14.62	0.66	8.49

Source: Adapted from Takyi et al. (1977)

[a] A considerable percentage of the fine roots could not be recovered in the Malmo.

[b] Reseeded 23 days after the others.

[c] ND = No data. Root yields were too low to recover.

Table 20.5. Dry matter yields of legume species grown on tailings sand-peat-overburden (2:1:1) mix and tailings sand-peat (1:1) mix with and without lime. Second seeding.

Species	Yield (g/pot)[a]			
	Tops 2:1:1 Mix		+ Roots 1:1 Peat Mix	
	Nil pH 7.41	+ Lime 7.57	Nil pH 4.20	+ Lime pH 6.30
Cicer milk vetch	0.77	0.80	0.53	1.42
Sainfoin	3.08	4.89	0.60	3.38
Dawn Alsike	8.85	11.97	4.21	15.50
Alfalfa	7.77	7.99	2.60	6.94

Source: Adapted from Takyi et al. (1977)
[a] Yield is average of two replicates.

soils. Complete fertilizer (NPKS) increased yields but no further improvement resulted from addition of lime or micro-elements. Low pH is blamed for slightly lower yields on unlimed treatments.

The results of the individual studies by Takyi et al. (1977) should be assessed by the reader in relation to the methodology utilized.

Rowell (1977b) examined areas seeded by GCOS (Berry and Klym 1974) in 1971. After five years these areas continued to require fertilization; Festuca and some Bromus were still dominant.

Fertilizer greatly influenced the relative percentage of grasses and legumes in yields. As would be expected, fertilizer greatly favored grasses. Rowell (1977a, 1978) examined the sites of Berry and Klym (1974) and Berry (1970) further. Higher fertilizer rates appeared to be resulting in an increase in Bromus inermis at the expense of Festuca rubra. The plots fertilized at the highest rates contained almost pure Bromus; legumes were effectively absent. On intermediate fertilizer plots Bromus was slowly replacing Festuca and Agropyron cristatum, and Trifolium hybridum and Melilotus were being eliminated. Where no fertilizer had been applied since 1974 poor growth had occurred and growth was mostly Festuca.

A number of grass and legume species were tested under various fertilizer treatments beginning in 1976 (Rowell 1977b). Again Bromus was favoured by increasing fertilizer, at the expense of all other species, and was dominant in all treatments. However, three Agropyron species performed fairly well (Table 20.6; Rowell 1978).

The effect of fertilization on the dominance of Bromus relative to other grasses and legumes in this study (Rowell 1978) has been documented through 1978. On unfertilized plots Festuca competed better and legumes increased (Rowell 1979; Tables 20.7 and 20.8). Other experimentation in the same study showed similar results except that Poa and Agropyron performed better on low-fertilization plots. For the Agropyron this is not in accordance with results from earlier in the study, which indicated that Bromus suppresses or eliminates these species under a continued moderate to high fertilizer regime.

Table 20.6. Percentage cover estimates for plant species in seed mix used to revegetate a tailings sand dike, Fort McMurray, Alberta.

Plant Species	Fertilizer Treatment[a] (increasing fertilizer) % Mean		
	A	B	C
Smooth Brome	34	47	62
Hard Fescue	6	4	1
Kentucky and Canada Blue Grass	8	9	4
Streambank and Slender Wheatgrass	21	18	14
Pubescent Wheatgrass	22	20	17
Red Top	< 1	< 1	< 1
Altai Wild Rye	< 1	< 1	< 1
Cicer Milk Vetch	6	1	< 1
Alfalfa Rhizoma	3	1	0
Sanfoin	< 1	< 1	0
Lupine[c]			
Pendek Oats[c]			

Source: Rowell (1978)

[a] For treatment description the reader is referred to the original publication.

[b] Values are averages of three replicates from treatments 1, 5, 6 and 7.

[c] Always 0.1% cover (Treatment 1).

Table 20.7. Assessment of percentage cover by different seeded grasses and legumes during May and October 1978, Fort McMurray, Alberta.

Treatment	Percentage Cover					
	Brome Grass	Creeping Red Fescue	Crested Wheatgrass	Sweet Clover	Alfalfa	Alsike Clover
May 1978						
T_o[a]	4	92	0	3	1	0
T_oA	54	45	0	1	0	0
T_1	87	13	0	0	0	0
T_1A	98	2	0	0	0	0
T_2	98	2	0	0	0	0
T_2A	99	1	0	0	0	0
T_3	91	9	0	0	0	0
T_3A	100	0	0	0	0	0
T_4	82	18	0	0	0	0
T_4A	93	6	1	0	0	0
T_5	24	75	0	1	0	0
T_5A	72	28	0	0	0	0
October 1978						
T_o	5	72	0	6	3	13
T_oA	45	47	0	2	2	4
T_1	98	2	0	0	0	0
T_1A	98	2	0	0	0	0
T_2	99	1	0	0	0	0
T_2A	99	1	0	0	0	0
T_3	96	3	0	1	0	0
T_3A	100	0	0	0	0	0
T_4	88	10	2	0	0	0
T_4A	97	1	2	0	0	0
T_5	33	58	0	0	0	9
T_5A	80	20	0	0	0	0

Source: Rowell (1979)
[a] See Table 20.2 for treatment description.

Table 20.8. Assessment of percentage cover by different seeded grasses and legumes, between 1974 and 1978, Fort McMurray, Alberta.

Treatment[a]	Species Distribution (% Cover)														
	Creeping Red Fescue					Brome Grass					Alfalfa and Alsike Clover				
	1974	1975	1976	1977	1978	1974	1975	1976	1977	1978	1974	1975	1976	1977	1978
T_0	90	100	88	88	72	9	0	9	1	5	1	0	3	11	23
T_2	90	93	50	23	1	9	7	50	77	99	1	0	0	0	0
T_4[b]	90	92	69	32	10	9	8	25	67	88	1	0	1	0	2
T_5	90	96	80	74	58	9	4	19	24	33	1	0	1	2	9

Source: Adapted from Rowell (1979)

[a] Fertilizer treatment totals:

	T_0	T_2	T_4	T_5
	1971 through 1974	1971 through 1978	1971 through 1975, 1977	1971 through 1978
Total N	279	639	639	449
Total P	138	230	230	183
Total K	188	548	548	276
Total S	0	9	18	67

[b] T_4 contained 5% Crested Wheatgrass in 1976.
" 1% " " " 1977.
" 2% " " " 1978.

Studies of potential use in dike stabilization were carried out in Lesser Slave Lake Provincial Park at an elevation of 576 m on low (3 m), gently rolling sand dunes created by stabilization with snow fencing (Lesko 1974b). Dunes contained no organic matter and had a low moisture holding capacity and nutrient content.

Plants were seeded between 03 to 11 May, 1973. Plots were hydromulched using: (1) 225 kg/ha fertilizer (10-30-10 and 40-0-0); (2) 225 kg/ha Milorganite; (3) 75 to 100 L/ha Curasol AK; (4) 162 L/ha curasol AH; and (5) 79 to 140 kg/ha Tylose 666.

Species used are shown in Table 20.9. Relative cover and biomass index (height X area covered) are shown in Tables 20.10 and 20.11, respectively. All grasses and legumes were from commercial sources, except native clumps of Elymus sp.

Dune crests had significantly less vegetation cover than other topographic positions (approximately one-third cover). Cover on north-west and south-east aspects, and between dunes was not significantly different.

Agropyron cristatum cv. Nordan provided the best cover during the first year. Calamovilfa longifolia and Oryzopsis hymenoides showed the poorest performance. Recommended agronomic grass species were Elymus junceus, Agropyron desertorum, A. trichophorum, A. cristatum, Festuca arundinacea, and Lolium perenne.

Of the five legumes, only Onobrychis sativa performed suitably. Other species, despite having more seed per unit volume, exhibited poor germination and growth (except Melilotus sp.).

Elymus giganteus has been used to stabilize dunes in the Pacific North West. A total of 29 000 culms per hectare were machine planted; hand planting at 30.5 x 30.5 cm spacing was carried out on rough areas. Spacing and plants per hill were adjusted to site severity. E. giganteus is non-palatable and is more successful than shrubs (Schwendiman 1977).

In Australia Secale cereale followed by Medicago sativa worked well on dunes (Mitchell 1974) but most other species used in Australia are not suitable for use in Alberta.

Table 20.9. Grass and legume species used in dune revegetation, Lesser Slave Lake Provincial Park.

Species	Common Name
Agropyron cristatum (L.) Gaertn.	Fairway wheatgrass
Agropyron dasystachyum (Hook.) Scribn.	Thick spike wheatgrass
Agropyron trichophorum (Link) Richt.	Pubescent wheatgrass
Agropyron desertorum (Fisch.) Schult.	Nordan wheatgrass
Festuca rubra L.	Red fescue
Festuca scabrella Torr.	Rough fescue
Festuca ovina var. duriuscula A. Gray	Hard fescue (Durar)
Festuca arundinacea Schreb.	Alberta fescue
Lolium perenne L.	Perennial ryegrass
Poa compressa L.	Canada bluegrass
Poa glaucantha Gaudin	Bluegrass
Calamovilfa longifolia (Hook.) Scribn.	Prairie sandreed
Oryzopsis hymenoides (Roem. and Schult.) Ricker	Indian ricegrass
Elymus junceus Fisch.	Russian wild-rye
Melilotus sp.	Sweet clover 1-7007
Astragalus cicer L.	Cirer milk vetch
Coronilla varia L.	Crown vetch
Onobrychis sativa Lam.	Sainfoin
Lotus corniculatus L.	Bird's Foot Trefoil

Source: Lesko (1974b).

Table 20.10. Average biomass index for grasses and legumes in all topographic positions of dunes - Lesser Slave Lake Provincial Park.

Species	Biomass Index[a]
Russian wild-rye	78761
Native sod clumps	71280
Nordan wheatgrass	51739
Sainfoin	20428
Pubescent wheatgrass	20351
Alberta fescue	19264
Fairway wheatgrass	16609
Perennial ryegrass	16082
Thick spiked wheatgrass	8652
Indian ricegrass	8499
Sweetclover	7429
Hard fescue	6657
Red fescue	4771
Prairie sandreed	2591
Crown vetch	1900
Bluegrass	1732
Trefoil	1445
Cicer milk vetch	1439
Rough fescue	1306
Canada bluegrass	1189

Source: Lesko (1974b).

[a] Any two means not connected with the same line are significantly different at the 95% probability level.

S = 5393

Table 20.11. Average cover of grasses and legumes in descending order in all topographic positions on dunes - Lesser Slave Lake Provincial Park.

Species	Area Covered[a] cm^2
Nordan wheatgrass	2759
Pubescent wheatgrass	1949
Sainfoin	1948
Russian wild-rye	1767
Perennial ryegrass	1737
Alberta fescue	1631
Native sod clumps	1377
Fairway wheatgrass	1271
Hard fescue (Durar)	1019
Red fescue	757
Thick spiked wheatgrass	714
Sweetclover	350
Crown vetch	244
Prairie sandreed	236
Cicer milk vetch	188
Indian ricegrass	186
Trefoil	165
Rough fescue	157
Bluegrass	142
Canada bluegrass	111

Source: Lesko (1974b).

[a] Any two means not connected with the same line are significantly different at the 95% probability level.
S = 242.23

Work on China clay tailings in England is relevant to oil sands work. Tailings are sandy though coarser (40% of particles greater than 2 mm) than oil sand tailings, pH is 5 to 5.5 and cation exchange capacity (CEC) is greater than 2 meq/100 gm. Climate is, of course, much less severe. Grass legume mixes work well on these tailings (Handley et al. 1978). Following initial stand establishment, organic matter production can be maintained or increased by regular N fertilization to promote grasses or by reduced N and increased P which favors legumes (Handley et al. 1978; Johnson, McNeilly and Putwain 1977). Nitrogen transfer from legumes to grass can apparently be enhanced by cutting or grazing. Clover does not persist with fertilizer rates of 100 kg N/ha/a. Trifolium repens is susceptible to toxic effects of NH_4^+ and H_2PO_4. NPK at 60-26-49 kg/ha produced 60% initiation of Trifolium repens establishment in a greenhouse. Protective peat mulch reduced mortality. Release of N by vegetation is low (1 to 4% turnover/a) where grasses are the main vegetation. Mineralization is much higher where Trifolium is a significant component of the sward. Rates of weight loss from buried grass and clover in the field (Lanning and Williams 1979) decreased in the order: clover roots > clover shoots > grass shoots > grass shoots. In the short term (this study), only clover contributed to mineralized N. Loss of above-ground parts by wind and water erosion can significantly reduce contribution of N by legumes. A large proportion of mineralized N is volatile (Lanning and Williams 1980) and much may be leached. These processes reduce N transfer from clover to grasses.

20.1 SUMMARY

Festuca rubra and Bromus inermis are obvious proven species for the oil sands region. The composition of these species can be regulated by fertilizer treatment. Where Festuca rubra dominates the initial stand it can maintain dominance even under continued fertilization. With equal opportunity, Bromus inermis will dominate Festuca rubra under high levels of fertilization.

Agropyron (A. riparium, A. trachycaulum, A. trichophorum) should receive more attention as they are obvious candidates for revegetation in the region. Other species that deserve attention include A. cristatum and A. desertorum, Elymus junceus, Lolium perenne and Festuca arundinacea. Elymus giganteus may also be worthy of attention for special situation.

Medicago sativa and Onobrychis spp. appear to be the most promising legumes for the region; however, more research is required on Onobrychis.

The response of agronomic species of grasses and legumes is still not well understood with respect to interspecific competition and in relation to fertilization. Use of irrigation as a cultural treatment is not conclusive.

Future research in the Oil Sands region must be related to soil and amendment research.

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21. USE OF AGRONOMIC GRASSES AND LEGUMES IN REVEGETATION OF THE MOUNTAINS AND FOOTHILLS REGION

Considerable work has been carried out with agronomic species in mountain and foothills areas of Alberta. In the Luscar area (altitute 1650 to 1680 m) two grass/legume mixtures were tested on prepared sandstone and shale overburden (Etter 1971). The mixes and rates (kg/ha) used were: Mixture (1) Agropyron cristatum 33.6 kg/ha, Agrostis alba 11.2 kg/ha, Festuca rubra 33.6 kg/ha, Poa pratensis 11.2 kg/ha, Melilotus alba 22.4 kg/ha; and Mixture (2) Agropyron riparium 13.4 kg/ha, Bromus inermis 16.8 kg/ha, Elymus junceus 16.8 kg/ha, Phleum pratense 16.8 kg/ha, Medicago sativa 16.8 kg/ha. Results are presented in Table 21.1. Plant densities were considered adequate for erosion control on all but 70 to 76% slopes and appeared to be limited by suitable microsites rather than rate of seeding or species mixture.

Later studies (Lesko, Etter and Dillon 1975) examined three additional species mixes on the Luscar site (Site 1; Table 21.2) and eleven mixes seeded on shale spoil on a second site having 10 to 20% slopes (Site 2; Table 21.3). Sites were prepared by grading or were bulldozed and packed. The seed mixes contained both native and introduced grasses, legumes, trees, shrubs, and forbs. A hydroseed slurry was used comprised of:

Water	1.1 l/m^2
Wood fibre	90 to 110 g/m^2
Inorganic fertilizer 10-30-10	22.6 g/m^2
Urea 46-0-0	11.0 g/m^2
Activated sewage	22.6 g/m^2

Most evaluation was done for mixes. However, several individual introduced grass species performed well on Site 2 (Table 21.4).

Introduced species did not establish as well on Site 1. Dactylis glomerata, Bromus inermis, Phleum pratense, Medicago sativa and Melilotus alba were considered "successful" but no quantitative data were presented.

Table 21.1. Plant densities (plants/0.8 sq. m) of legumes and grasses seeded in the fall and spring on four slopes at Luscar, Alberta.

Plants	Seeding Time	Slope (%)			
		0 to 6	13 to 21	33 to 39	70 to 76
LEGUMES					
Sweet Clover	Fall '70	6.7[a]	3.2	4.7	0.8
	Spring '71	72.8	97.1	13.9	1.7
Alfalfa	Fall '70	2.0	0.6	1.2	0.2
	Spring '71	61.6	50.6	38.2	0.8
GRASSES					
Mix I	Fall '70	273.0	115.0	164.0	8.3
	Spring '71	161.0	158.0	55.0	4.5
Mix II	Fall '70	139.0	66.6	37.8	16.9
	Spring '71	213.0	118.0	73.7	5.0

Source: Etter (1971).

[a] Values are the means of counts on six, 0.8 sq m plots on 29 June 1971 and 27 July.

Table 21.2. Species used in fall 1970/spring 1971 seeding at site No. 1, Luscar, Alberta.

Mix	Species[a]	Common Name
1	Agropyron cristatum (n)	crested wheatgrass
	Agrostis alba (i)	red top
	Festuca rubra (i)	creeping red fescue
	Melilotus alba (i)	white sweet clover
	Poa pratensis (i)	Kentucky bluegrass
2	Agropyron riparium (n)	streambank wheatgrass
	Bromus inermis (i)	smooth brome
	Elymus junceus (i)	Russian wild rye
	Medicago sativa (i)	alfalfa
	Phleum pratense (i)	timothy
3	Abies balsamea (n)	balsam fir
	Picea glauca (n)	white spruce
	Pinus contorta (n)	lodgepole pine
	Caragana arborescens (i)	caragana
	Eleagnus commutata (n)	silverberry
	Prunus padus (i)	mayday
	Prunus virginiana (n)	chokecherry
	Fraxinus pennsylvanica (i)	green ash
	Cotoneaster interessima (i)	cotoneaster
4	Agropyron bakeri (n)	baker wheatgrass
	A. latiglume (n)	
	A. repens (n)	couchgrass
	Koeleria cristata (n)	junegrass
	Oryzopsis hymenoides (n)	indian millet
	Dryas drummondii (n)	dryas
	Epilobium angustifolium (n)	fire weed
	Linaria dalmatica (i)	toad flax
	Phacelia sericea (n)	scorpion weed
5	Agropyron inerme (n)	beardless wheatgrass
	A. riparium (n)	streambank wheatgrass
	A. smithii (n)	western wheatgrass
	A. trichophorum (i)	pubescent wheatgrass
	Dactylis glomerata (i)	orchard grass
	Festuca scabrella (n)	rough fescue

Source: Lesko, Etter and Dillon (1975).

[a] n -- native
i -- introduced

Table 21.3. Seed mixtures used in the surface treatment and mulch test at Site No. 2, Luscar, Alberta.

Mix 1
- Agropyron cristatum (n)[a, b]
- Amelanchier alnifolia (n)
- Aster alpinus (n)

Mix 2
- Agropyron latiglume (n)
- Prunus virginiana (n)
- Lonicera tartarica (I)

Mix 3
- Agropyron riparium (n)
- Poa pratensis (I)
- Rosa woodsii (n)

Mix 4
- Pinus contorta, var. latifolia (n)
- Agropyron trichophorum (n)
- Caragana arborescens (I)

Mix 5
- Agrostis alba (I)
- Medicago sativa (I)
- Lupinus sp. (Russel) (I)

Mix 6
- Bromus inermis (I)
- Melilotus alba (I)

Mix 7
- Picea glauca (n)
- Dactylis glomerata (I)
- Vicia americana (n)
- Cornus stolonifera (n)

Mix 8
- Picea engelmannii (n)
- Elymus junceus (I)
- Elaeagnus commutata (n)

Mix 9
- Festuca rubra (I)
- Phleum pratense (I)
- Epilobium angustifolium (n)

Mix 10
- Koeleria cristata (n)
- Phacelia sericea (n)
- Linaria dalmatica (I)

Mix 11
- Picea engelmannii (n)
- Agropyron cristatum (n)
- Phleum pratense (I)
- Caragana arborescens (I)
- Epilobium angustifolium (n)
- Linaria dalmatica (I)
- Pinus contorta (n)
- Bromus inermis (I)
- Rosa woodsii (n)
- Medicago sativa (I)
- Phacelia sericea (n)

Source: Lesko, Etter and Dillon 1975.

[a] (n) -- native
(I) -- introduced

[b] species is classed as introduced by many authors.

Table 21.4. Establishment rate for introduced species as percentage of possible maximum germinants after one growing season at Site No. 2, Luscar, Alberta.

Species	Possible Max. No. of Germinants per m^2	Established Plants[a] per m^2		Establishment Percent		
		A	B	A	B	Mean
Bromus inermis	523	50	63	11.5	12.0	11.8
Agropyron trichophorum	523	23	79	4.4	15.1	9.8
Dactylis glomerata	491	52	44	10.6	9.0	9.8
Phleum pratense	529	29	72	5.5	13.6	9.6
Elymus junceus	512	38	58	7.4	11.3	9.4
Poa pratensis	289	14	32	4.8	11.0	7.9
A. cristatum	452	20	43	4.4	9.5	7.0
Melilotus alba	105	6	3	5.7	2.8	4.2
Festuca rubra	485	16	20	3.3	4.1	3.7
Medicago sativa	94	3	0	3.2	0.0	1.6
Agrostis alba	414	6	1	1.4	0.2	0.8

Source: Lesko, Etter and Dillon (1975).

[a] A -- on bulldozer-packed soil
B -- onrough-graded soil

Macyk has carried out research on the McIntyre Mine lease area since 1972 (Macyk 1974, 1977a,b, 1978a,b, 1979a,b; Macyk and Steward 1977). The mine is located at approximatley 1615 m elevation. The experimental plots were established on unconsolidated and weathered mineral material ("topsoil") low in N and P with pH values of 7.0 to 7.9 (later referred to as moderately to slightly acid).

Early results suggested that Agropyron cristatum cv. Fairway, Elymus junceus cv. Sawki, Bromus inermis cv. Carlton, Festuca rubra cv. Boreal, Agropyron intermedium, Lolium perenne, A. trachycaulum, F. ovina var. duriuscula, Poa pratensis cv. Nugget and F. rubra cv. Erica were suitable for reclamation on the site if heavily fertilized at establishment.

Later results (after five years and at least one more heavy application of N-P-K) favoured Festuca rubra, F. ovina var. duriuscula, F. rubra cv. Arctared, Agropyron cristatum, Elymus junceus, Bromus, Phleum pratense, Medicago sativa, and Lotus corniculatus.

In 1977, monospecific plots were set up on fly and bottom ash (mix). Medicago sativa cvs. Rambler and Chimo, Trifolium hybridum, Agropyron riparium, Alopecurus arundinaceus, and A. pratensis performed best. It was recommended, however, that ash be covered with a layer of topsoil. These plots were later destroyed by erosion.

At the second site, species performance was similar to the above on raw topsoil. However, after a dry year A. pratensis, Agropyron riparium, and Medicago cv. Beaver performance decreased and Trifolium repens had disappeared. Yields of legumes ranged from 201.5 g/m^2 for Lotus corniculatus to 683.8 g/m^2 for Medicago cv. Rambler on unfertilized plots. Yields for grasses ranged from 296.3 g/m^2 for Agropyron tricophorum to 576.2 g/m^2 for Bromus inermis cv. Carlton. Alopecurus pratensis and Medicago cv. Beaver apparently did not establish on unfertilized plots. No statistical comparison of yields was carried out.

Preliminary results (Macyk 1978b) showed that Festuca ovina var. duriuscula, Alopecurus pratensis, F. rubra, and Elymus junceus performed well and appealed to wildlife (sheep). Others not grazed by

sheep included Agropyron cristatum, A. riparium, and Bromus. Medicago (cvs. Drylander and Rambler), Lotus corniculatus and Trifolium hybridum are recommended legumes.

Suggested mixtures for south facing aspects and drier sites include Festuca spp., Agropyron spp., Elymus junceus, and a legume. Mixtures for north and east facing aspects should contain lesser amounts of Festuca and Agropyron but should include Bromus spp. and Phleum pratense plus a legume. Medicago sativa and Lotus corniculatus are more suitable to drier sites while Trifolium hybridum is more suitable to moist sites.

The reader is advised to read the original reports for details of Macyk's work. Throughout the study, many treatments were added or modified and it is difficult to critically summarize the data.

Studies in British Columbia reported that survival of grass-legume mixtures above the treeline is dependent upon fertilizer application, mainly because legumes do not otherwise survive. Below the treeline, legumes performed well without fertilizer and enhanced the growth of grasses. Seeding rates were not standard and were approximate with untested modifications based on common sense. Species performance is best described by a quote directly from the article (British Columbia Ministry of Energy, Mines and Petroleum Resources 1978:44):

"Above treeline, grass species performance was excellent for meadow foxtail, good for creeping red fescue and timothy, and moderate for meadow bromegrass. Redtop grows well the first season but has a poor ability to overwinter. Legume growth was very poor above treeline. The only two legume species which grew at all were alsike and red clover and these only grew in sheltered moist pockets.

"Below treeline, growth of grass and legume species was generally good for the majority of species tested. Growth was excellent for creeping red fescue and redtop; good for Canada bluegrass, slender wheatgrass and timothy; and moderate for meadow foxtail, bromegrass and meadow fescue. Legume growth was excellent for

alfalfa, alsike clover, red clover, sweet clover and white clover. Birdsfoot trefoil and sainfoin grew poorly."

At Hat Creek, British Columbia materials from a coal test pit were segregated into seven types plus fly ash. The material was spread to a depth of 1 m and one half of each plot was covered with 5 cm of "topsoil". Three seed mixes of four species each were sown on each plot in 1977. No fertilizer was used. An evaluation of individual species and species mixes is presented in Table 21.5. These results are very preliminary (one year of data) (Hathorn, Docksteader and McQueen 1979).

Additional plots with slopes of 22°, 26°, and 30° were also constructed and tested with Seed Mix #1. A different topsoil was used and the plots were hydroseeded. Plant establishment was best on the 30° slope and no erosion occurred on any plots.

Selner (1973, 1975) tested a number of introduced grasses and legumes in alpine sites at Caw Creek Ridge, Alberta. Only four Festuca and one Poa species were evaluated highly after two years (Table 21.6).

Studies in the mountain states must be viewed with some caution because of soil and climatic differences, but obviously some of the successful species there should be considered for reclamation in Alberta. The studies reviewed were of two types: mountain mine reclamation, and roadside revegetation.

Work by Kenny and Cuany (1978) in Colorado illustrated the site specific effects of high altitude (subalpine) reclamation. Tests of a number of agronomic grasses and legumes on several sites of 3048 to 3414 m elevation showed more consistency of performance of different grasses within sites than individual grasses between sites. Festuca varieties did perform relatively well on most sites (Table 21.7). It is interesting that the seed mix used by industry in earlier reclamation attempts at Climax, Colorado (Brown 1974) contained most of the species which did well in this study. However, the study by Kenny and Cuany did turn up additional species.

Table 21.5. Seed mix and species performance on plots at Aleece Lake in the Hat Creek area, British Columbia.

Grass or Legume (Variety)	Performance	% By number of Seeds	Comments
Seed Mix I[a]			
Crested Wheatgrass (N)	moderate to poor	41	performed best (biomass)
Canada Bluegrass	poor (poor seed suspected)	29	because of performance of fall rye
Alfalfa (Drylander)	poor-(excessive competition from fall rye?)	26	
Fall Ryegrass (annual)	superior to all other species (may have inhibited other species however)	4	
Seed Mix II[b]			
Russian Wild Ryegrass	did well on all but carbonaceous material, good performance on sodic material	39	good interspecific compatibility; Highest total density
Slender Wheatgrass	emergence success like crested w.g. but more robust growth and better spike development	18	
Sainfoin (Melrose)	performed best of all legumes	25	
Sweet Clover	low density - may have been due to competition	18	
Seed Mix III[c]			
Smooth Bromegrass (Manchar)	did well on better soils, moderately well on best	19	performance (biomass and density) similar to seed Mix II

continued ...

Table 21.5. Concluded.

Grass or Legume (Variety)	Performance	% By number of Seeds	Comments
Streambank Wheatgrass	did quite well on more difficult soils	39	
Canada Bluegrass (Rubens)	did poorly	14	
Double Cut Red Clover	performance about same as alfalfa. May have suffered from competition	28	

Source: Hathorn, Docksteader and McQueen (1979).
[a] Application rate = 5 kg/ha
[b] Application rate = 108 kg/ha
[c] Application rate = 48 kg/ha

Table 21.6. Evaluation of legumes and grasses tested at Caw Creek Ridge, Alberta at 1981 m elevation in Alpine Tundra Zone.

Species	(Scale 1 to 10, 10 is best) Evaluation[b] 1972	Evaluation 1973	Percent survival 1973
Timothy, Sport (Phleum nodosum)	5	2	10
Timothy, Evergreen (P. nodosum)	5	2	15
Timothy, Itasca (P. pratense)	5	4	40
Timothy, Toro (P. pratense)	8	3	20
Timothy, S 51 (P. pratense)	5	2	5
Orchardgrass, Tardus II (Dactylis glomerata)	8	2	5
Orchardgrass, Chinook (D. glomerata)	10	3	20
Ryegrass, Barenza (Lolium multiflorum)	5	3	20
Fourwing saltbush (Atriplex canescens)	1	1	0
Canada bluegrass, Common (Poa compressa)	7	2	15
Kentucky bluegrass, Nugget (P. pratensis)	8	7	ND
Sainfoin, Krasnodar (Onobrychis spp.)	4	1	0
Cicer milkvetch (Astragalus cicer)	4	1	0
Tall oatgrass (Arrhenatherum elatius)	8	2	5
Reed canarygrass, Rise (Phalaris arundinacea)	7	3	30
Russian wildrye (Elymus junceus)	9	2	ND
Bromegrass, Polar (Bromus inermis)	5	5	60
Bromegrass, Baylor (B. inermus)	9	2	ND
Creeping red fescue, Arctared (Festuca rubra)	9	10	95
Creeping red fescue, Reptans (F. rubra)	7	6	75
Hard sheep fescue, Durar (F. ovina var. duriuscula)	9	10	95
Chewings fescue, Erica (F. rubra var. commutata)	10	9	85
Rough fescue (F. scabrella)	4	3	30
Tall fescue (F. arundinacea)	5	2	5

Source: Adapted from Selner (1973, 1975)

Table 21.7. Evaluation of grass and legume species tested at several high elevation sites in Colorado.

Specific Name	Common Name	Named Variety	Breckenridge 3261 m	Climax 3414 m			Leadville Fall 1974 3048 m			Leadville Spring 1975 3048 m			Urad July 1974 3231 m		Urad October 1974 3231 m		Winter Park 3231 m		
			76	75	76	77	75	76	77	75	76	77	76	77	76	77	75	76	77
LARGE GRASSES:																			
Agropyron dasystachyum	Thickspike wheatgrass		++	+	+	++	++	.	.	.	+	+++	+	++	.	..	.		0
A. desertorum	Crested wheatgrass	Ruff	-	-	-	-	.	0	0	.	0	0	-	-	+.	+.	-	-	-
A. riparium	Streambank wheatgrass	--		+.	+	++	-	-	-	-	-	-	+.	++.	-	-	+	+.	.
A. smithii	Western wheatgrass	Arriba		+	+	+	++	0	0	.	.	+.	..	.	-	-	.	+	+
		Rosana	++	+	+.	+	-	-	-	-	-	-	++	+	-	-	.	+	.
A. trachycaulum	Slender wheatgrass	Primar	+++	+	+	+.	-	-	-	-	-	-	++	++.	-	-	+	..	++
Alopecurus arundinaceus	Creeping foxtail	Garrison		.	+	+	.	+	+++	.	0	0	+	+.	+.	+	0		0
A. pratensis	Meadow foxtail	--		+	+	++.	-	-	-	-	-	-	+.	++.	-	-	++		++.
Bromus inermis	Smooth brome	CSU-1		+	++	++.	-	-	-	-	-	-	++	+.	-	-	++	++	++
		Lincoln	-	.	+	+.	+	+	0	+.	0	0	+	+.	+	..	-	-	-
		Manchar	++	+.	+.	++	++	0	0	+.	.	0	++.	++.	+.	+.	++	++	++.
		Polar		.	.	+	-	-	-	-	-	-	..	..	-	-	+	+	++
B. marginatus	Mountain brome	Bromar	+	+	+	+	-	-	-	-	-	-	+	..	-	-	+		.
Dactylis glomerata	Orchardgrass	Nordstern	-	-	-	-	++	+	++	..	0	0	-	-	++.	++	-	-	-
		OSG-7		+	+	+	-	-	-	-	-	-	++	++	-	-	+	++	0
		--		++	++	++.	-	-	-	-	-	-	++.	++.	-	-	+	++	0
Festuca arundinacea	Tall fescue	Fawn		+	+	++	-	-	-	-	-	-	+	+.	-	-	.		0
Phalaris arundinacea	Reed canarygrass	--	-	.	.	+.	.	0	0	.	.	+.*	+	+	+.	++	-	-	-
Phleum pratense	Timothy	--	+	+.	++	++.	+	+	+++	.	+	-	+++	++.	++	++	+++	+++	++.
Stipa viridula	Green needlegrass	Source 1		0	0	0	.	0	0	.	0	0	0	0	.	.	+		0
		Source 2	-	0	0	0	+	.	+++	.	.	-	.	.	.	.	-	-	-
SMALL GRASSES:																			
Agrostis alba	Redtop	--		.	.	.	-	-	-	-	-	-	..	.	-	-	.		0
A. palustris	Creeping bent	Seaside	+++	..	+	..	.	.	.	.	0	0	+	+	.	..	.		0
Deschampsia caespitosa	Tufted hairgrass	--	-	-	-	-	.	.	++.*	.	0	0	-	-	.	+	-	-	-
Festuca arizonica	Arizona fescue	Redondo	++	.	+	+	-	-	-	-	-	-	.	+.	-	-	0		0
F. ovina var *duriuscula*	Hard fescue	C-26	++	+	++.	+++	+.	+	+++	.	+	++	++	++.	++.	++.	+		++.
		Durar	++	..	+.	++	-	-	-	-	-	-	++	++	-	-	++		++

Continued

Table 21.7. Concluded.

Specific Name	Common Name	Named Variety	Breckenridge 3261 m 76	Climax 3414 m 75	76	77	Leadville Fall 1974 3048 m 75	76	77	Leadville Spring 1975 3048 m 75	76	77	Urad July 1974 3231 m 76	77	Urad October 1974 3231 m 76	77	Winter Park 3231 m 75	76	77
Small grasses (cont')																			
F. rubra	Red fescue	Dawson	++	+	++	++	+	.	+.*	.	+	0	++.	++	++.	++	++		++
		Illahee	++	+	++.	+.	+	++	+++	.	.	0	++	++	+.	+.	+		+.
		Pennlawn	++	..	++	+.	..	+	+++	.	+	++	++	++	++	+.	+		+.
		Wintergreen	++	..	+.	++	++	..	++	..	+	++	++.	++.	++.	++	++		++
		--	++	+	+++	+.	-	-	-	-	-	-	++.	++	-	-	++		++
		--	-	.	+.	++.	++	+	++.*	+	++.	++.	+++	++.	+++	++.	-	-	-
P. rubra var. *commutata*	Chewing's fescue	--	-	-	-	-	.	0	0	.	0	0	-	-	+	+	-	-	-
Poa compressa	Canada bluegrass	--	-	-	+	++	.	0	0	.	0	0	+	+	+.	+.	-	-	-
P. pratensis	Kentucky bluegrass	Nugget	-	.	+	+.	-	-	-	-	-	-	++	+++	-	-	+		+++
		Park	++	.	+	+.	.	0	0	.	0	0	+++	+.	+++	+.	.		+
P. compressa x *P. pratensis*		NJE-167		.	+	+.													
FORBS AND LEGUMES:																			
Astragalus cicer	Cicer milkvetch	Lutana	++	..	++	+++	-	-	-	-	-	-	+++	++	-	-	0		0
		Oxley	+++	.	++	+.*	-	-	-	-	-	-	+++	++.*	-	-	0		0
		Size 12	+	.	.*	+++	-	-	-	-	-	-	++	+++	-	-	0		0
Atriplex canescens	Fourwing saltbush	--	-	0	0	0	0	0	0	..	0	0	0	0	-	-	-	-	-
Medicago sativa	Alfalfa	Ladak			+.	+++	+.	-	-	-	-	-	++.	++.	-	-	.		0
		Nomad	-	-	++	++.	.	.	++	++	.	++	++	++	..	++	-	-	-
		Apredor	-	-	-	-	-	0	0	++	.	+.*	-	-	+.	+	-	-	-
		Madrid	-	+	+++	0	.	0	0	.	.	0	+++	0	0	0	-	-	-
Melilotus officinalis	Yellow sweetclover	--	-		0	0	0	0	0	+++	0	0	0	0	+++	0	-	-	-
Sanguisorba minor	Small burnet	--	-		.	.*	+.*	..	-	-	-	-	+++	+++	-	-	..		+++
Trifolium ambiguum	Kura clover	--		.	.*	+.*	..	-	-	-	-	-	+++	++.*	+.*	+++	-	-	-
T. hybridum	Alsike clover	--	-	+	0	0	0	0	0	.	0	0	+++	++.*	-	-	.		++
T. medium	Zigzag clover	--	++	.	.*	++	.	-	-	-	-	-	++	+.*	-	-	.		++
T. repens	White clover	--			+.	++	+.	0	0	+	0	0	+++	++	.	+	+++		++

Source: Kenny and Cuany (1979:89-90)

Legend:
0 = None present
. = Poor growth
+ = Fair growth
++ = Good growth
+++ = Excellent growth

+ = Only a few plants present
.. = Poor to fair
+. = Fair to good
++. = Good to excellent
- = Not planted

The authors illustrated the need for supplemental fertilizer at the time of planting, as in the British Columbia studies (British Columbia Ministry of Energy, Mines and Petroleum Resources 1978), with the addition of topsoil also being beneficial. Studies at Climax advised fertilizer additions every two years, with P being very important. Urea formaldehyde did not appear to release sufficient N to satisfy plant requirements. Festuca was better adapted to nutrient poor conditions than large grasses. Some comments by Kenny and Cuany (1978:95) on site specific adaptations of species are as follows:

"Some of the species...have particular adaptive characters: reed canarygrass does best in moist sites; orchardgrass in protected sites which are snow covered in winter; the Kentucky bluegrass and the smooth brome both show spread out of the rows. The fescues stay green later into the season than the other grasses with no apparent effect on their over-winter survival. Timothy has the advantage of being small seeded and hence can get into cracks readily.

"The legumes are all difficult to establish. Better establishment and survival may be obtained in fall seedings. Crownvetch is a new entry which looks good from the aspect of being ungrazed by the small mammals and occasional deer and elk feeding in our plots. Alfalfa is the most grazed species. The biennial yellow sweet clover does best at lower elevations where it can reseed itself."

Native legumes have not done well as forage in Colorado. Introduced species have been selected for high elevation (Townsend 1974). Trifolium pratense (Swedish orgin) has persisted for two to five years and is site specific. Medicago sativa has done well and persisted at all sites.

The Beartooth Plateau of Montana has been heavily disturbed by various exploration and mining activities. Disturbed areas are characterized by shallow soil, a 60 to 70 day growing season, and 114 to 152 cm of precipitation.

Results of studies (Brown et al. 1976) indicated that introduced species do well for one or two seasons but are eventually outperformed (vigour, cover, production, density) by natives. In a

grass plug transplant study, Brown and Johnston (1978) again found that the native species generally outperformed the introduced species. The authors noted that the encouraging survival of Poa compressa (91%) and Alopecurus pratensis (72%) should be viewed with caution as they had only presented the first year's results. Fertilizer (high N and P) is essential for early establishment and performance; the addition of organic matter alone was not sufficient to ensure survival.

Berg (1974) reported information from past observations of reclamation in subalpine locations (2743 to 3048 m). Favourable species were Alopecurus pratensis and A. arundinaceus. Bromus inermis performed well if highly fertilized. Phleum pratense did not produce seed at higher elevations. Commerical Agropyron trachycaulum would not set viable seed. Festuca arundinacea, Dactylis glomerata and Lolium perenne were very competitive. Festuca rubra may do well in upper subalpine sites that have long periods of snow cover.

Test plots were established at four altitudes (1250 to 2000 m) in the east Cascades of central Washington (Klock, Tiedemann and Lopushinsky 1975). These were single species plots seeded at 328 seeds per square metre for small seeded species and 130 for large species. Legumes were not inoculated. Plots were fertilized with 336 kg/ha 16-20-0-15 for two years. Soils were predominantly sand, pumice, and sandstone. Performance of all species is indicated in Table 21.8.

Only Dactylis glomerata, Phleum pratense, Lolium perenne and Bromus inermis performed satisfactorily on all sites. Other species were site specific and success of species decreased with increasing elevation. Eleven species became established only within restricted elevations and soil types; species and areas on which their use is not recommended are:

Festuca arundinacea	above 1830 m elevation
F. ovina var. duriuscula	above 1830 m elevation
F. ovina	above 1525 m elevation and on coarse pumice soils

Table 21.8. Foliar cover on experimental plots for selected grasses, legumes and shrubs, one and two years after planting in the East Cascades of Central Washington.[a]

Common Name	Scientific Name[b]	Variety	Seeding Rate kg/ha	Percent Cover							
				Binkelman Ridge		Sugarloaf Corral		Handy Springs		Silver Creek	
				1971	1973	1972	1973	1972	1973	1972	1973
Perennial Grasses:											
Orchardgrass	*Dactylis glomerata*	Latar	10.8	50	42	70	72	37	32	30	40
Tall fescue	*Festuca arundinacea*	Alta	61.7	54	67	68	53	38	1	45	28
Hard fescue	*Festuca ovina* var. *duriuscula*	Durar	10.4	42	25	16	40	15	0	1	20
Sheep fescue	*Festuca ovina* var. *ovinoa*		5.4	14	33	0	5	3	0	0	3
Smooth brome	*Bromus inermis*	Manchar	30.2	2(8)[c]	40(3)	27(0)	33(10)	2(0)[d]	0(0)	15(0)	23(0)
Beardless wheatgrass	*Agropyron inerme*	Whitmar	48.4	34	25	13	18	0	0	0	1
Intermediate wheatgrass	*Agropyron intermedium*	Amur	75.3	2	15	42	45	25	7	0	17
Intermediate wheatgrass	*Agropyron intermedium*	Greenar	58.4	52	42	57	28	18	0	28	17
Pubescent wheatgrass	*Agropyron trichophorum*	Topar	64.1	5	7	43	15	20	0	2	3
Siberian wheatgrass	*Agropyron sibiricum*		28.7	18	0	15	0	0	0	0	0
Slender wheatgrass	*Agropyron trachycaulum*	Primar	45.3	20	38	0	13	17	0	32	27
Streambank wheatgrass	*Agropyron riparium*	Sodar	40.9	0	0	2	3	0	0	0	30
Tall wheatgrass	*Agropyron elongatum*	Alkar	81.7	66	87	29	2	0	0	3	13
Thickspike wheatgrass	*Agropyron dasystachyum*		33.3	8	8	12	7	0	0	28	25
Big bluegrass	*Poa ampla*	Sherman	64.6	42	83	43	2	8	0	35	46
Canada bluegrass	*Poa compressa*		2.4	0	0	15	28	18	47	4	30
Indian ricegrass	*Oryzopsis hymenoides*		30.8	0	0	0	0	0	0	0	0
Perennial ryegrass	*Lolium perenne*		27.9	13	27	85	88	42	48	40	38
Timothy	*Phleum pratense*	Drummond	4.3	34	32	62	53	38	42	38	15
Blue wildrye	*Elymus glaucus*		41.9	0	0	0	0	0	0	0	0
Russian wildrye	*Elymus junceus*		43.1	0	0	0	0	0	0	0	0
Black medic	*Medicago sativa*		27.6	0	0	--	--	--	--	--	--
Sids oats grama	*Bouteloua curtipendula*		30.5	0	0	--	--	--	--	--	--
Lodora green needlegrass	*Stipa viridula*		21.5	0	0	0	0	0	0	0	0
Common green needlegrass	*Stipa viridula*		33.0	0	0	--	--	--	--	--	--
Annual Grasses:											
Common ryegrass	*Lolium* sp.		26.6	2(8)	0(0)	22(0)	30(1)	0(0)	0(0)	(--)[d]	--
Wheat	*Agropyron triticum*		172.8	30(3)	0(0)	13(10)	0(0)	0(2)	0(0)	(--)[d]	--
Cereal rye	*Secale cereale*		109.8	32(5)	0(0)	30(10)	0(0)	17(5)	0(0)	(--)[d]	--
Legumes:											
Clear milkvetch	*Astragalus clear*	Clear	46.3	0	0	0	0	0	0	0	0
Red clover	*Trifolium pratense*	Mammoth	25.8	0	0	0	0	2	0	0	0
Yellow sweet clover	*Melilotus officinalis*		29.8	0	0	1	0	0	0	0	0
Birdsfoot trefoil	*Lotus corniculatus*		12.6	0	0	0	0	0	0	0	0
Bramble vetch	*Vicia sandfolia*		22.2	0	0	0	0	0	0	0	0
Common vetch	*Vicia sativa*	Oder	50.6	3(0)	0(0)	3(1)	0(0)	5(5)	0(0)	(--)[d]	--
Shrubs:											
Antelope bitterbrush	*Purshia tridentata*		265.4	0	0	--	--	--	--	--	--

Source: Adapted from Black, Tiedemann and Lopushinsky (1975)

[a] All plots were fertilized with ammonium phosphate sulfate (16-20-0-15) at the rate of 336 kg/ha.

[b] Scientific names are according to Harland P. Gilkey and William A. Dayton, Standardized plant names. 675 p. J. Horace McFarland Company, Harrisburg, Pa., 1942.

[c] Percent plant cover in another experimental plot of same plant variety but not fertilized is in parentheses.

[d] Experimental plot disturbed by tractor operation.

Poa ampla	above 1830 m elevation
P. compressa	below 1370 m elevation
Agropyron inerme	above 1525 m elevation and on coarse pumice soils
Agropyron intermedium cv. Amur	on coarse pumice soils
A. intermedium cv. Greenar	on coarse pumice soils
A. trachycaulum	above 1370 m elevation
A. elongatum	above 1675 m elevation and on coarse pumice soils
A. dasystachyum	above 1370 m elevation

The failure of many species to become established at higher elevations appears to relate to their susceptibility to damage from frost heaving, cold air and soil temperatures, short growing season, and high solar radiation levels.

Mixing of species had the disadvantage of affecting (reducing) yields of some species.

Research from Australian and New Zealand situations may not be considered relevant to Alberta by many people because of obvious differences in soils and climate in particular. However, a suprising number of species have shared similar successes and failures.

Successful species in alpine and subalpine areas of Australia (Bryant 1971) have been:

1. Trifolium repens, established at an altitude up to 1829 m by the use of: (1) an inoculation technique which places a number of rhizobia in close contact with seed and protects them with a lime coating, (2) an improved fertilizer mixture, and (3) suitable cultivars.
2. Agrostis spp: Agrostis tenuis cv. Highland and A. palustris cvs. Penncross and Seaside are promising for alpine revegetation. Below 1524 m A. tenuis cv. Browntop is of value on drier exposed sites.
3. Festuca rubra var. commutata is slow to establish and

does not contribute significantly to the stabilizing vegetation until the second and third seasons.

4. Poa pratensis does best on moist, medium textured soils of moderately high fertility in the montane and subalpine tracts.
5. Lolium perenne is suitable for temporary cover. It has weak perenniality at above 1524 m and is unable to regenerate in the alpine and subalpine areas.
6. Nurse crops.

   Avena sativa cvs. Cooba and Avon have stooled well and produced a softer straw more prone to being bent over by winter snow to give a more effective mulch. Not satisfactory above treeline.

   Secale montanum, autumn sown, has produced strong-strawed plants with little stooling at elevations up to 2103 m. Lack of dense stooling, stiff, erect straw, and avid competition for available nitrogen appear to be the main disadvantages.

In New Zealand, some strains of North American species have been used successfully in montane areas (Ritchie 1973, 1978). Species such as Dactylis glomerata, Festuca rubra var. commutata and Agrostis tenuis performed well. Details of trials were skimpy and sites were not always comparable to those commonly found in Alberta, most New Zealand sites being warmer and moister. Results appeared to be quite site specific and response to fertilizer was not constant. However, these studies serve to emphasize the wide area of potential utilization of these species.

Dunbar (1971) reported performance of species on plots fertilized with a very complete fertilizer (superphosphate 502 kg/ha; magnesium sulphate 125.5 kg/ha; potassium sulfate 125 kg/ha; copper sulfate 11.2 kg/ha; sodium molybdate 0.35 kg/ha).

Grasses and legumes on test plots deteriorated without maintainance fertilizer over five seasons. However, Agrostis tenuis, Trifolium repens, and Holcus lanatus reproduced from seed. Agrostis

tenuis and Festuca rubra var. commutata persisted best with no fertilizer (Dunbar 1970a). While fertilizer response is very site specific, sites fertilized with 29 kg/ha of magnesium carbonate all responded well in terms of plant vigour and cover and persistent cover (Dunbar 1974). Potassium was also found to provide a significant response, especially in combination with magnesium (Dunbar 1970b).

A considerable number of studies have been carried out in Canada's Arctic region in an attempt to solve reclamation problems related to disturbances caused by pipelines and other resource developments. Much of this research is relevant to revegetation problems in the alpine areas of Alberta.

In testing over 30 commercial varieties at Prudhoe Bay, Alaska, virtually all species declined in cover from the first growing season to the second (Mitchell and McKendrick 1974). Only Festuca sp. cv. Arctared and Poa pratensis cv. Nugget demonstrated the ability to withstand at least one winter but it was questionable whether these species could maintain themselves in an artic environment without periodic fertilization. Germination of commercial species did not seem to be less than natives in the arctic environment.

Other attempts to reclaim disturbed tundra and taiga sites are reported for Alaska (Van Cleve 1973). Establishment and growth of Lolium sp., Festuca cv. Arctared, F. ovina var. duriuscula cv. Durar, Poa sp. cv. Icelandic, Poa sp. cv. Nugget and Agropyron trachycaulum was good on disturbed sites of less cold areas of Alaska. Heavy fertilizer (448 kg/ha 8-32-16) resulted in a marked response because of low nutrient release on cold soils. The sites being reclaimed were not particularly harsh.

Mitchell (1973) tested varieties of 13 genera on a variety of sites in Alaska, basically divided into two categories--Boreal and Tundra. Cultivars developed in Alaska performed best. Mesic Boreal sites were favourable for many grasses of all 13 genera. On wetter, acid, peaty sites, Alopecurus pratensis, Festuca, and Phleum did very well while Agropyron, Elymus, Bromus, and Puccinellia performed poorly. Dry sites were less restrictive as Bromus, Festuca, Alopecurus

pratensis, Agropyron, and Elymus performed well. Tundra sites proved to be more restrictive than Boreal sites and alpine tundra proved more favourable than arctic tundra. Festuca, Poa, Alopecurus. prantensis, and Phleum varieties were the most promising introduced species.

On all sites studied by Mitchell (1973, 1976) fertilizers were found to be essential. At least 561 kg/ha supplying 30 to 56 kg was advisable. Van Cleve and Manthei (1971) indicated that high nitrogen (2:1:1) fertilizers were best. Mitchell's work suggested that more research is needed on fertilizer application.

Agronomic cultivars also require some management in harsh northern environments. Van Cleve (1977) reported that fertilizer (high P) was needed for introduced species but often could not offset severe environmental effects (Figures 21.1 and 21.2, Table 21.9). He also reported that even the best introduced species tended to show a marked decline in cover production five years or so after seeding. It may be necessary to reseed prior to takeover by natives, which may require 4 to 10 years depending upon seed-bed and seed resource.

Klebesadel (1973) has published a report which provides lists of recommended native and introduced species suitable for reclamation in Alaska. Unfortunately, there are no data matching species varieties to site conditions.

The Arctic Land Use Research (ALUR) program sponsored many research projects on tundra sites in the early to mid seventies. Studies with non-native grasses again indicated the value of P and NP fertilization. Lime alone or N alone had little effect. Plots established at Inuvik, Tuktoyaktuk, and Norman Wells (Hernandez 1973a, b) in 1970 were examined in 1972. Results were highly variable between localities but Poa pratensis cv. Nugget, and Festuca rubra cv. Arctared were consistently the best agronomic performers overall. Fertilizer effects were often lost by the second or third year. Species such as Phalaris arundinacea cv. Frontier, Phleum pratense cv. Engmo, Agropyron cristatum cv. Fairway, and Dactylis glomerata cv. Kall tended to overwinter poorly and die out.

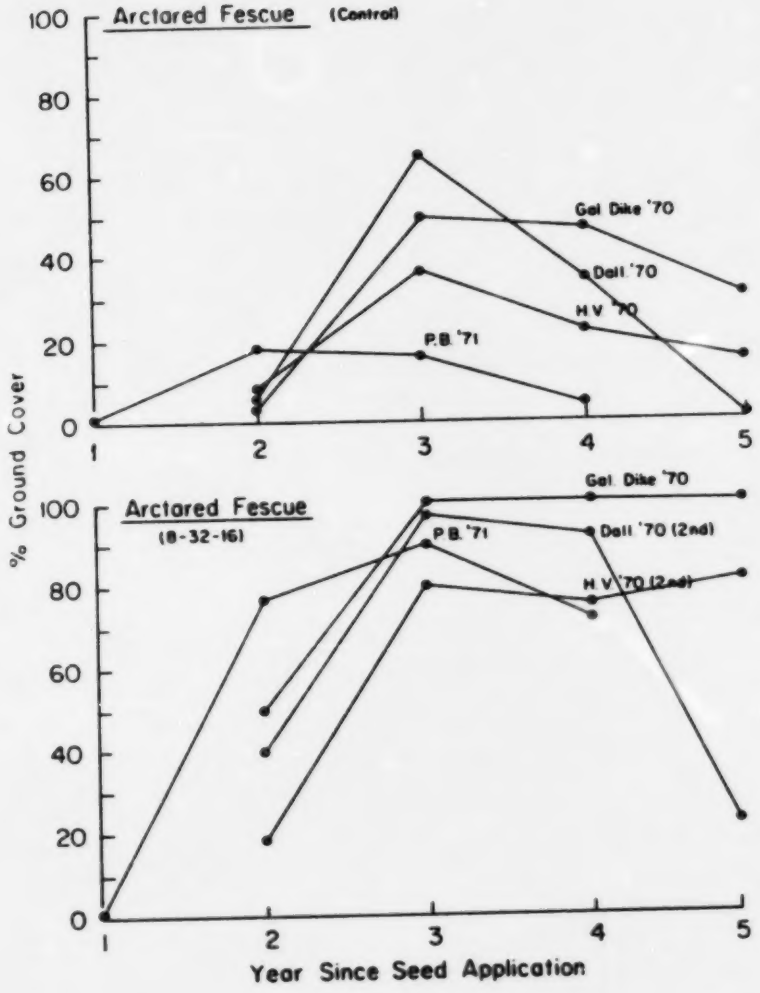

Figure 21.1. Average cover production for arctared fescue at respective study sites with no fertilizer application and application of high phosphate fertilizer (8-32-16) at rate of 444 kg/ha at time of seeding. Seed applied at rate of 44 kg/ha. Second fertilizer application at same rate made at Happy Valley and Dall sites in 1972. Standard error of mean ranges from 10% to 20%. Year of seed application is indicated beside site abbreviation.

Source: Van Cleve (1977)

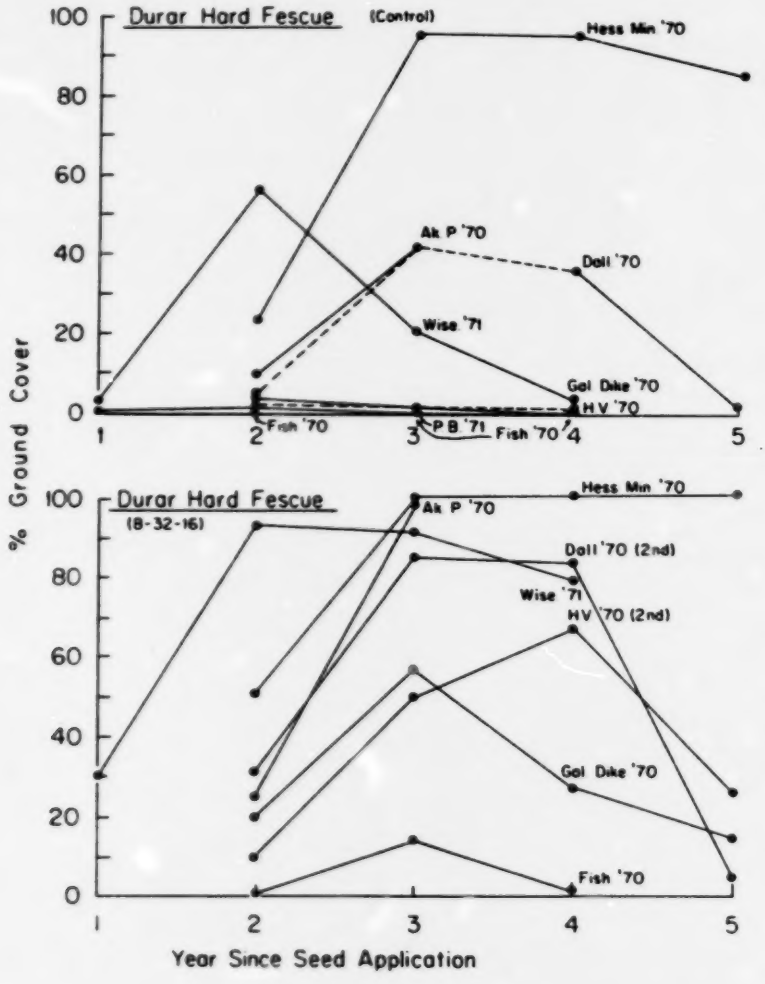

Figure 21.2 Average cover production for durar hard fescue at respective study sites with no fertilizer application and application of high phosphate fertilizer (8-32-16) at rate of 444 kg/ha at time of seeding. Seed applied at rate of 28 kg/ha. Second fertilizer application at same rate made at Happy Valley and Dall sites in 1972. Standard error of mean ranges from 10% to 20%. Year of seed application is indicated beside site abbreviation.

Source: Van Cleve (1975)

Table 21.9. Cover production (%) after at least four years for best species tested at revegetation study sites in Alaska.

Study area	Arctared[a] Fescue	Boreal Creeping Red Fescue	Durar Hard Fescue	Nugget Poa	Meadow Foxtail	Slender Wheat Grass	Hair Grass	Climax Timothy
Prudhoe Bay	72 ± 3 [b] (7 ± 2)[c]	0	0	ND	0	ND	62 ± 10 (trace)	trace (trace)
Happy Valley	82 ± 7 (14 ± 8)	24 ± 11 (trace)	27 ± 12 (0)	ND	4 ± 2 (trace)	ND	ND	0
Pump Station 3	ND[d]	ND	ND	44 ± 15 (2 ± 1)	ND	62 ± 11 (6 ± 4)	ND	ND
Galbraith Lake	100 ± 0 (31 ± 17)	0	0	0	0	32 ± 16 (10)	95 ± 0 (13 ± 9)	0
Anaktuvuk Pass	ND	ND	ND	100 ± 0 (60 ± 19)	ND	76 ± 5 (10 ± 10)	ND	ND
Wiseman	ND	13 ± 3 (7 ± 2)	78 ± 2 (4 ± 3)	0	53 ± 23 (6 ± 5)	ND	0	2 ± 2 (trace)
Fish Creek	ND	13 ± 4 (1 ± 1)	0	ND	0	ND	ND	0
Dall Summit	23 ± 3 (1 ± 1)	3 ± 1 (2 ± 1)	6 ± 2 (2 ± 1)	1 ± 1 (trace)	0	trace (trace)	22 ± 12 (trace)	trace (trace)
Hess Creek	ND	58 ± 14 (22 ± 4)	100 ± 0 (88 ± 5)	trace (trace)	23 ± 18 (12 ± 3)	0	ND	10 ± 6 (trace)

Source: Van Cleve (1977)

[a] Seeding rates in kg/ha: arctared fescue, 44; boreal creeping red fescue, 42; durar hard fescue, 28; nugget poa, 22; meadow foxtail, 48; slender wheat grass, 32; hair grass, 14; climax timothy, 13.

[b] Mean ± standard error for fertilizer treatment (8-32-16).

[c] Mean ± standard error for control.

[d] Species not tested at this site.

Trials on berms in the arctic tested species on organic soils, gravel soils, and silty mineral soils. Festuca rubra cv. Arctared and Poa pratensis cv. Nugget, along with F. rubra cv. Boreal were again the best performers (Table 21.10). Performance was best on mineral soil berms and worst on gravel (all species less than 9% cover). On warm berms performance was about doubled and Trifolium hybridum cv. Aurora, and Medicago sativa cv. Falcata grew almost as well as grasses. Cereal nurse crops (Secale cereale and Avena sativa) had little effect on grass and legume cover. The reduced success of southern species was attributed to incomplete preparation for winter due to improper periodicity. South into the boreal forest, Alopecurus pratensis, Agropyron trachycaulum, and Phleum pratense cv. Engmo performed well for two years.

Successful introduction of agronomic seed into native communities appears unlikely. Younkin and Friesen (1976) and Younkin and Martens (1976) tested species established on pipelines in 1971. Successful agronomics excluded native species, while natives invaded on unsuccessful sites (e.g., Agropyron cristatum test plot) (Table 21.11). Fertilizer trials on grass/legume seed mixes indicated no effect of increased rate on agronomics relative to natives (0, 100, 200, 300 kg/ha of 24-24-0). However, first year cover production was significantly increased (over control) by the high rate. Refertilization with 500 kg/ha of 20-20-10 significantly increased production (Table 21.12) of many species. It is interesting to note the position of Poa pratensis cv. Nugget, Festuca rubra cvs. Arctared and Boreal considering the earlier performance of these species (Hernandez 1973a, b).

The work on the arctic pipeline was reported in various, sometimes unrelated, formats. Results were difficult to interpret as some data, including that on fertilizers, were not adequate for a comprehensive assessment.

Revegetation research with agronomic species on low elevation foothills sites in Alberta has been minimal, possibly because these sites are less severe than those in other areas, particularly the oil

Table 21.10. Ranking of the species tested over berms at three test sites in the Arctic.

Species	Site[a] and Rank[b]					
	Prudhoe Bay	Inuvik	Norman Wells Cold	Norman Wells Hot	Mean[c] Rank	Overall[d] Rank
Arctared creeping red fescue	1	5	1	1.5	2.08	1.5
Boreal creeping red fescue	3	1	2	1.5	2.12	1.5
Nugget Kentucky bluegrass	2	4	3	4.5	2.71	3
Meadow foxtail	4	6	6	7	5.33	4
Climax timothy	9	2	7	6	6.04	5
Sawki Russian wildrye	10.5	3	4	9	6.67	8
Frontier reed canarygrass	10.5	8	10	8	8.75	9.5
Fairway crested wheatgrass	7	9	8.5	10	8.71	9.5
Falcata alfalfa	8	7	5	4.5	6.38	6
Aurora alsike clover	5	10	8.5	3	6.58	7
Leo birdsfoot trefoil	6	11	11	11	9.79	11

Source: Hernandez (1973b)

[a] Site: Prudhoe Bay, 25°F gas loop; Inuvik, 150+°F oil loop; Norman Wells, gas loop - Cold, 15°F; Hot, 65°F.

[b] Ranking based on cover at each berm position, except top, at each site. When cover was the same for several species, the ranks involved were averaged and each species was given the same value.

[c] Mean rank included the individual rankings shown and the rankings obtained from total cover of each species at each site.

[d] Overall rank based on mean rank values, with those differing by less than 0.05 being deemed equal.

Table 21.11. Mean % cover of seeded and invading species on the seed and fertilizer test plots over test section I and II at the Sans Sault site, North West Territories, 1971 to 1975.

		Meadow Foxtail	Creeping Red Fescue	Fowl Bluegrass	Kentucky Bluegrass	Frontier Reed Canarygrass	Sheep Fescue	Meadow Fescue	Canada Bluegrass	Creeping Bentgrass	Streambank Wheatgrass	Redtop	Rough Bluegrass	Slender Wheatgrass	Colonial Bentgrass	Tall Fescue	Intermediate Wheatgrass	Tall Wheatgrass	Crested Wheatgrass
Living	1971	63.3	33.0	57.3	22.3	63.5	21.0	27.8	35.3	53.8	12.5	57.5	45.0	32.5	52.0	34.3	23.5	18.5	16.8
	1972	84.4	53.4	61.0	42.5	43.1	27.0	46.3	28.9	57.8	28.5	14.7	21.8	32.4	40.0	8.2	17.1	15.9	8.5
	1973	40.2	47.4	38.3	31.3	32.5	39.4	26.7	29.6	24.3	11.2	19.0	20.3	21.8	0.7	7.1	0.6	0.2	0.1
	1974	21.8	30.4	8.3	17.8	23.2	45.4	14.3	12.7	24.0	4.3	10.2	10.2	2.8	4.5	1.2	0	0	0.1
	1975	16.0	11.0	11.4	10.8	13.7	26.2	12.3	8.0	2.2	2.6	5.0	8.8	1.1	2.4	2.5	0.3	0	0
Cover by Native Vasculars	1971	0.1	0.5	0.2	0.2	0	0.2	0.6	0.4	0.4	0.2	0.2	0.6	0.3	0.3	0.2	0.1	0.6	0.2
	1972	0	0.4	1.1	0.2	0	1.3	0	0.8	0.1	1.9	0.4	0.4	0.4	0.1	2.5	1.2	0.4	2.6
	1973	0	6.8	0.6	0.2	0.1	1.2	0.2	0.7	0.1	6.6	1.2	1.8	2.6	2.0	4.8	0.6	15.0	11.6
	1974	0.2	1.4	4.0	1.4	1.6	0.5	0.2	6.8	1.7	12.0	9.6	6.4	16.0	9.9	8.6	17.4	22.1	27.6
	1975	1.0	3.7	5.0	2.1	3.3	2.0	0.9	15.9	6.5	12.3	9.4	13.0	17.3	17.2	14.9	25.9	25.8	25.6

Source: Adapted from Younkin and Friesen (1976)

[a] Seeded species are listed (left to right) in order of importance based upon total seeded cover.

Table 21.12. Mean shoot production (g/m^2 oven dry wt. ± S.E.) and % increase with refertilization of grasses on test section I at the Sans Sault Test Site, Northwest Territories (August 1973).

Species	Refertilized (500 kg/ha 20-20-10)	Not Refertilized	% Increase
Rough Bluegrass	297.6 ± 8.6	44.8 ± 20.8	564[a]
Creeping Bentgrass	829.3 ± 157.9	168.0 ± 23.5	394[a]
Streambank Wheatgrass	480.0 ± 136.0	114.7 ± 29.3	318[a]
Slender Wheatgrass	588.0 ± 147.7	146.4 ± 13.9	302[a]
Meadow Foxtail	640.0 ± 62.4	164.0 ± 5.9	290[a]
Tall Fescue	197.3 ± 41.6	53.3 ± 40.3	270[a]
Meadow Fescue	773.9 ± 160.5	220.0 ± 39.4	252[a]
Kentucky Bluegrass	489.1 ± 84.6	141.9 ± 21.3	245[a]
Redtop	1032.0 ± 136.8	320.0 ± 60.6	222[a]
Colonial Bentgrass	586.7 ± 128.3	186.7 ± 29.9	214[a]
Fowl Bluegrass	716.0 ± 130.7	405.9 ± 21.4	76
Crested Wheatgrass	157.8 ± 67.8	96.0 ± 49.4	64
Sheep Fescue	512.0 ± 26.2	314.7 ± 72.5	63
Canada Bluegrass	386.6 ± 85.8	242.6 ± 85.8	59
Intermediate Wheatgrass	208.0 ± 34.6	148.8 ± 53.6	40
Tall Wheatgrass	212.8 ± 26.4	154.7 ± 61.0	38
Reed Canarygrass	597.9 ± 57.6	557.9 ± 29.8	7
Creeping Red Fescue	378.1 ± 25.3	455.5 ± 93.9	-17
x ± S.E.	501.6 ± 57.2	218.6 ± 33.1	+56%

Source: Younkin and Friesen (1976).
[a] Significant at the 95% level.

sands and alpine areas. Erosion is a major problem in this region, particularly along roads and seismic lines.

Two-and-one-half years' experience (Goff 1971) in the Swan Hills area of Alberta provided the following recommendations for species use:

Species	Rating
Phleum cv. Climax	Excellent
Festuca rubra	Good but requires continuous moisture for best growth. Dense root system makes it desirable for erosion control.
Poa pratensis	Similar to Festuca rubra but expensive and in short supply.
Agropyron cristatum	Good plant on well drained arid sites.
Trifolium repens and T. pratense	Adapted to Grey Wooded and Black soils. Requires ample moisture and drainage.
Trifolium hybridium	Similar to above but not as expensive ($0.55/kg as compared to $2.64 in 1973).
Medicago sativa cv. Rambler	Useful on dry land. Creeping root. Drought resistant and winter hardy. Germinates well.

Some species mixes were suggested but modifications are ongoing.

Several species were tested on levelled granular coal at the Shaugnessy Coal Mine near Lethbridge, Alberta (1067 to 1219 m elevation) (Rutten 1972). Agropyron trachycaulum, A. cristatum cv. Fairway, Festuca arundinacea, F. rubra, Poa pratensis, P. pratensis cv. Park, Medicago sativa cvs. Rambler and Vernal, and Melilotus sp. were sown with several amendments in June. No quantitative results were presented but the report indicated that both varieties of Medicago sativa and Melilotus were the only species to do well on all irrigated plots. A similar study (Regier 1974) at Blairmore, Alberta examined a

seed mixture of Melilotus sp. and Trifolium hybridum, Medicago sativa, Agropyron trachycaulum and A. cristatum, Festuca rubra, Phleum pratense, Bromus inermis, Secale cereale,, Triticum aestivum and Hordeum vulgare. Grass/legumes were sown at twice the agricultural rate and cereals at half the rate. Plots were spray irrigated. Secale cereale was the dominant species followed by Festuca rubra and legumes.

21.1 SUMMARY

Numerous species have been tested in mountain and foothill sites. Research is best summarized with respect to the performance of each.

Festuca rubra. At least 18 trials were reviewed that tested F. rubra (Boreal, Reptans, Brica, Arctared, Commutata, and possibly others) in mountainous regions. The species has been rated as a good to excellent reclamation species in Alberta, British Columbia, Montana, Alaska, Australia, New Zealand, and in the arctic taiga and tundra.

This species performs well at all elevations to 3000 m elevation in Montana and to 2225 m elevation in Alberta. It generally performs well above and below the treeline although it is not always successful in harsh or high elevation sites. At very high elevations snow cover is critical to its establishment.

The species does not require maintenance fertilizer and does better in competition without it. However, it is slow to establish. While F. rubra has been established successfully on wet, acid peats as well as on dry areas, it probably does best on "good to moderate" areas (soil fertility, climate, moisture). In boreal areas, it has been found to require continuous moisture.

Festuca ovina. Tested in Alberta, Washington State, and Alaska, F. ovina performed poorly above 1500 m elevation in Washington but performance was acceptable at 2225 m elevation in Alberta. Performance was not acceptable on carbonaceous materials. "Durar" seems to be the best variety.

Bromus inermis. This species was tested in about nine trials in Alberta, British Columbia, Montana, Washington State, and Alaska. Research has been carried out in boreal, taiga, and tundra regions.

Success has been moderately successful above and below the treeline. Performance has been good on dry sites; poor on wet, acid peaty soils. Best performance occurs on "good" sites.

B. inermis performs well in a mix but generally requires fertilization.

Poa pratensis. P. pratensis was studied in about eight trials in Alberta, British Columbia, and Australia. The species has been tested in boreal, taiga, and tundra regions. It has performed well up to 2225 m elevation in Alberta but does best below the treeline. Poa performs very well in taiga and tundra areas, where it has consistently been rated the "best" species. In boreal areas, the species requires continuous moisture.

The "Nugget" variety appears to be the most promising.

Phleum pratense. This species has been tested in about 10 trials primarily in boreal, taiga, and tundra regions. Mainly Engmo and Climax varieties have been used. P. pratense performs very well on wet, acid, peaty soils but will not overwinter in arctic (tundra) regions. Performance has been good above treeline but it did not set seed in trials at 2700 to 3000 m in Montana.

Agrostis alba. A. alba was tested in four trials in Alberta and British Columbia. Performance in Alberta has been poor. In British Columbia performance was excellent below the treeline but poor above the treeline.

Agropyron trachycaulum. A. trachycaulum was tested in Alberta and in arctic and boreal regions. It has performed well in the boreal and at elevations of 1675 m in Alberta. It did not overwinter in Arctic tests.

Agropyron riparium. Tests in Alberta, British Columbia, and Alaska indicated poor performance on dry sites at 1615 m elevation but also acceptable performance at a similar elevation. The species apparently does well on "poor" soils.

Dactylis glomerata. This species has been tested in Alberta, Montana, Washington State, and New Zealand and has generally been quite successful. It was found to be good on all sites tested at 1200 to 2000 m elevation in Washington, was very competitive at 2700 to 3000 m elevation in Montana and persisted with no fertilizer in New Zealand. Only one trial was reported for Alberta and the species deserves more attention.

Alopecurus pratensis. Eight studies were reviewed from Alberta, British Columbia, Alaska, and Montana and from boreal, tundra, and taiga regions. The species performed well on dry sites in Alaska but poorly on a dry site at 1615 m elevation in British Columbia. Elsewhere in British Columbia and in Montana, excellent performance was reported above the treeline. In taiga and tundra areas, A. pratensis was noted as one of the "best" species. Performance was good on boreal sites, notably on wet, acid, peat soils.

A number of species were encountered infrequently in the literature and results were not consistent. Poa canadensis and Festuca elatior performed well below the treeline but the former performed poorly at high elevations. Lolium perenne performed well at 2700 to 3000 m elevation in Montana and at 1200 to 2000 m elevation in Washington. However, in Australia the species did not regenerate on alpine and subalpine sites. Agrostis tenuis performed well above 1825 m in Australia while cv. Browntop did well on dry sites below 1525 m. Elymus junceus was tested in Alberta, British Columbia, and Alaska and found to be generally a good performer except on wet, acid peats.

Other species tested infrequently with generally poor results included Poa cv. Iceland, Phalaris arundinacea cv. Frontier, Dactylis glomerata cv. Kall, Festuca arundinacea and Poa ampla.

Legumes have received far less attention than grasses at high elevation and require further research. Melilotus alba has been tested mainly in Alberta with fair to poor success at high elevation and excellent to good success at low elevations. Medicago sativa cvs. Beaver, Rambler, Dryland, and others have been tested with varied

success. There are obviously variety differences. Trifolium repens, T. hybridum, and T. pratense have generally performed well below the treeline and in boreal regions. A Swedish origin variety of T. pratense has been successful at high elevation; local varieties may do well on moist sites but may require fertilization. Lotus corniculatus and Onobrychis have quite varied success ("best" [Onobrychis] to poor) in mountain and arctic sites.

Fertilizers are generally required at the time of planting grasses. Even the best cultivars begin to show decline after five years in harsh northern climates. Fertilizer is required above treeline for legumes; below treelines legumes will perform well without fertilizer.

Site differences greatly affect species performance. Often there is more consistency between species within sites than between sites within species.

More research is required on Agropyron species differences and Medicago variety differences.

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22. USE OF AGRONOMIC GRASSES AND LEGUMES IN REVEGETATION OF THE PLAINS REGION

A great deal of work has been carried out in the Decker and Colstrip areas of Montana. Studies at Decker varied in the quality of the design and site preparation. Many projects initially established at Decker were discontinued (DePuit and Dollhopf 1978). The work at Colstrip was perhaps better planned and documented. There are far too many studies to give complete details; in addition, the work at both sites is still in progress and many results are inconclusive. Only highlights are presented here. The reader is advised to read the original references, and to obtain up-to-date progress reports (DePuit and Coenenberg 1979; DePuit and Dollhopf 1978; DePuit, Coenenberg and Willmuth 1978; Dollhopf and Majerus 1975; Richardson et al. 1975; Farmer et al. 1974; and Sindelar et al. 1974).

A test of five legume species at Colstrip indicated relative success and persistence. Plots were seeded with equal rates of pure live seed in May of 1975 and fertilized with 37 and 94 kg/ha of N and P_2O_5, respectively. Success of the five species on 22 June 1976 is shown on Table 22.1.

Onobrychis viciifolia cv. Eski and Medicago sativa cv. Spreader provided best resistance to invasion by Salsola kali. Astragalus cicer also performed well while Medicago cv. Ranger was less persistent and Lotus corniculatus unsuccessful.

Medicago cv. Ranger is noted for persistence and lack of aggressiveness in grass mixtures. Onobrychis has been shown to be comparable or superior to Medicago in terms of establishment and production on mine spoils but information on optimum season for seeding is not conclusive. The Eski variety is perferable for dry land situations but has limited nitrogen fixing ability. Astragalus cicer has a low, spreading form which provides good cover and erosion control. It is persistent, has high forage quality, and tolerance to grazing. However, it establishes slowly. Lotus corniculatus proved unsuitable for minespoil revegetation in Montana. DePuit, Coenenberg

Table 22.1. Success of five species of legumes, Colstrip, Montana, June 22, 1976.

Species	Plants density[a] (plants/m^2)	Aerial biomass[a] (kg/ha, dry weight)
Ranger alfalfa (*Medicago sativa*)	156 c	557.7 b
Spreader alfalfa (*Medicago sativa*)	248 b	1225.2 a
Eski Sainfoin (*Onobrychis vicifolia*)	216 bc	755.2 b
Lustana cicer milkvetch (*Astragalus cicer*)	361 a	597.1 b
Birdsfoot trefoil (*Lotus corniculatus*)	32 d	10.3 c

Source: Adapted from DePuit, Coenenberg and Willmuth (1978)

[a] Values followed by different letters not significantly different at 5% level (Newman-Kuel test).

and Willmuth (1978) provided a good review of the qualities of all five species.

A number of grass species were seeded at Colstrip on a ripped, topsoiled, disc plowed, cultipacked and harrowed site in October 1973. Species were seeded individually. Comparison of non-native species is given in Table 22.2. Results appeared to be highly site specific and greatly affected by initial erosion and sedimentation.

In studies at the Decker mine on poorly prepared topsoil of poor quality, Agropyron cristatum cv. Fairway, A. elongatum and Bromus inermis cv. Lincoln did moderately well, A. dasystachyum and A. cristatum cv. Nordan performed fairly well, and Melilotus officinalis, Medicago cvs. Ranger, Ladak and Vernal, and Onobrychis were the best producing legumes (Dollhopf and Majerus 1975).

In a test of three varieties of Agropyron (cvs. Fairway, Standard and Nordan) plus A. sibiricum broadcast at 56 kg/ha with fertilizer at 84 kg-N, 56 kg-P and 28 kg-K per ha all species produced good cover which nearly doubled in the second growing season and was maintained through the third (Dollhopf and Majerus 1975). In trials on better prepared spoil (good topsoil, chiselling, and harrowing, seeded at 1000 seeds/m^2), Agropyron cristatum, A. elongatum, A. sibericum, A. trichophorum, Elymus angustus, E. condensatus and E. junceus established well but decreased greatly in density by mid-summer. However, density still ranged from 30 to 180 plants/m^2. Medicago cvs Drylander, Ladak, and Ranger established with moderate density and Melilotus officinalis and Onobrychis viciifolia (Eske and Remont) had good density. The latter three and Medicago cv. Ranger decreased by about 50% by midsummer. Further evaluation (DePuit and Dollhopf 1978) proved Agropyron spp. as valuable species along with Bromus inermis cv. Lincoln. Of note was the decline of Elymus species. Medicago cvs. Ranger and Ladak and Melilotus officinalis were again the best legumes (Table 22.3).

Studies at Colstrip dealing with fertilizer and seeding time trials also illustrated the dominance of Agropyron cristatum and Bromus

Table 22.2. Mean rooted and canopy cover-derived frequency of 1973 plant species trials, Colstrip, 1977.

Species/Cultivar	Density May 1974 (Plants/m²)	Rooted Frequency	Cover Frequency	Notes
Agropyron cristatum	5	8[a]	12[a]	Most plots blown out and/or heavily thistle infested; poor plant vigour.
Agropyron elongatum	136	83	83	Tall, vigorous and evenly distributed.
Agropyron trichophorum	77	67	75	Low to moderate vigour; low to moderate plot thistle litter.
Bouteloua curtipendula	5	60	68	Very vigorous with ample seed production; low to moderate plot thistle litter.
Bromus arvensis	13	ND	ND	Seeded species not encountered.
Bromus brevis	0	9	9	Rarely encountered.
Bromus inermis	28	71	71	Evenly distributed, low to moderate vigour.
Dactylis glomerata	13	ND	ND	Seeded species not encountered.
Elymus angustus	167	69	79	Common and evenly distributed, low to moderate vigour.
Elymus junceus	13	12[a]	12[a]	Rare but vigorous when encountered; heavy thistle litter in certain plots.

continued ...

Table 22.2. Concluded.

Species/Cultivar	Density May 1974 (Plants/m²)	Rooted Frequency	Cover Frequency	Notes
Elymus triticoides	33	ND	ND	Seeded species not encountered.
Festuca elatior	8	ND	ND	Seeded species not encountered.
Festuca ovina var. duriuscula	3	7	7	Rare, but vigorous and headed out when encountered.
Phleum pratense	4	24	26	Rather sparse, moderately vigorous, producing seed.

Source: Adapted from DePuit, Coenenberg and Willmuth (1978).

[a] Data considered invalid due to plot disturbance (initial wind erosion, seed blowout, thistle infestation, etc.)

Table 22.3. Summary of percent plant canopy cover and frequency data for grass and legume species trails, Decker Coal Company, 1975. All data averages of three replicates.

	Seeded Species	Seeded (cover)	Species (Freq.)
Perennial	*Agropyron cristatum*	40.4	100.0
Grass Species	*Agropyron elongatum*	53.3	100.0
	Agropyron riparium[a]	43.0	100.0
	Agropyron sibericum	31.7	93.3
	Agropyron trichophorum	56.0	100.0
	Bromus inermis	22.9	93.3
	Dactylis glomerata	ND	ND
	Elymus angustus	1.3	6.7
	Elymus condensatus	1.0	13.3
	Elymus junceus	1.7	20.0
Legume Species	*Astragalus cicer*	1.5	46.7
	Lotus corniculatus	1.1	13.3
	Medicago sativa cv. Drylander	4.4	66.7
	Medicago sativa cv. Ladak	10.4	80.0
	Medicago sativa cv. Ranger	10.1	60.0
	Melilotus officinalis	9.1	66.7
	Onobrychis viciaefolia cv. Eski	2.5	33.3
	Onobrychis viciaefolia cv. Remont	2.0	26.7

Source: Adapted from DePuit and Dollhopf (1978).

[a]Species native to Montana

inermis but also that of Stipa viridula, the legumes Astragalus cicer, and Melilotus officinalis along with Medicago sativa (DePuit and Coenenberg 1979). Continued fertilization favored grasses and reduced legumes. In a study at the Decker mine in Montana (Farmer et al. 1974), Agropyron spp. and Bromus inermis dominated agronomic mix performance, although Bromus did not set seed.

Wintergraze and Hordeum have been used at Colstrip as temporary soil stabilizers in the establishment of perennial plant communities (DePuit, Coenenberg and Willmuth 1978). Wintergraze is a largely sterile hybrid resulting from a cross of Triticum with Agrotricum (a wheat/wheatgrass cross). While wintergraze is theoretically an annual, considerable second-year regrowth has been observed. There is some question regarding interference with establishment of perennials and also regarding the impact of various fertilizer regimes on wintergraze persistence and competition. Perennials were spring-sown into an established stand of wintergraze (second year), following chisel plowing which ripped up about half of the wintergraze. Low fertilizer rates (25 kg/ha N and 33 kg/ha P) provided good perennial grass and legume growth without producing excess wintergraze.

Some initial experiments in North Dakota (Barker, Ries and Nyren 1977) tested a variety of native and agronomic species of commercial availability. Trials were fertilized with 62 to 116 kg/ha N - P on agricultural land and sodic mine spoil, some covered by topsoil (15.24 cm). Grasses recommended for dryland seeding (Agropyron and Elymus) provided best stands and highest yields. Bromus inermis and Medicago did well, but decreased yield on minespoil, as opposed to agricultural soils and were greater than for Agropyron. Warm season species were difficult to establish and survival was poor (Table 22.4).

Studies in Colorado (Townsend 1974) have shown Medicago to be a species of excellent performance. Trifolium hybridum yielded well

Table 22.4. Seeding rates and established densities of forage grasses and legumes, sown at the Glenharold Mine, North Dakota.

Species	Seeding rate kg/ha	Seeding rate viable seeds/m	Untreated Spoil 1976 plants/m	15 cm Surface Soil 1976 plants/m
Cool-season grasses				
Wheatgrasses				
Steambank	28	167	17.6	21.8
Slender	37	112	17.1	18.0
Crested	25	112	14.2	15.1
Pubescent	40	112	11.3	14.2
Western	42	112	9.2	14.2
Fairway	18	112	10.9	11.7
Montana	42	112	16.3	11.3
Tall	53	112	11.3	10.9
Intermediate	34	112	9.6	10.1
Average			13.0 (29.4)[a]	12.5 (46.6)
Wildryes				
Russian	28	112	15.9	18.0
Altai	47	83	1.8	13.0
Canada	35	112	11.3	8.8
Basin	30	112	0.5	7.1
Beardless	57	112	7.5	3.8
Mammoth	50	83	10.4	2.9
Average			7.8 (20.5)	9.5 (37.3)
Miscellaneous				
Smooth bromegrass	29	112	30.5	26.3
Reed canarygrass	10	74	1.7	15.9
Hard fescue	14	167	0.0	15.1
Green needlegrass	35	112	13.8	12.5
Creeping foxtail	9	167	7.1	10.1
Mandan ricegrass	108	55	17.6	8.0
Nuttall alkaligrass	16	335	14.6	4.6
Prairie sandreed	40	167	0.5	3.8
Indian ricegrass	103	93	11.7	2.9
Alkali sacaton	8	333	0.8	2.2
Average			9.9 (23.0)	10.2 (30.4)
Warm-season grasses				
Blue gama	28	335	1.3	4.6
Sideoats grama	7	159	3.4	4.2
Deertongue	57	153	3.4	2.1
Big bluestem	29	112	5.4	1.3
Little bluestem	59	153	3.4	0.5
Switchgrass	16	153	0.0	0.5
Average			2.8 (8.2)	2.2 (17.7)
Legumes				
Alfalfa	15	112	5.9	4.6
Crownvetch	40	112	0.8	3.8
Sweetclover	22	112	2.1	2.1
Flatpea	54	18	0.0	0.8
Birdsfoot trefoil	14	112	3.8	0.5
Average			2.5 (7.0)	2.4 (14.1)

Source: Adapted from Barker, Ries and Myran (1977)

[a] Numbers in brackets are the 1974 averages.

but did not persist at low elevations. Trifolium repens, Onobrychis sp., Lotus corniculatus, and Vicia cracca did poorly at all plains locations.

The paper by Packer and Aldon (1978) presents very little data but is a general review of revegetation in the Great Plains areas. Suitable plant materials are suggested for the shortgrass and mixed grass prairies which would be suitable for the Brown Soil Zone of Alberta. There is very little shortgrass prairie in Alberta; however, species suggested for that region are Bromus inermis, Agropyron cristatum, and Elymus junceus. For the midgrass prairie, the above species plus Agropyron intermedium, A. trichophorum, and Melilotus officinalis have been successful. Species suited to alkaline-saline depressions are Agropyron elongatum, Sporobolus airoides, and Elymus junceus.

22.1 SUMMARY

Standard agricultural species and practices apply under normal circumstances in the plains region. Only special problem areas (e.g., sodic/saline spoils) require special treatment.

Wheatgrasses appear to be the best species for plains regions, particularly Agropyron cristatum, A. elongatum, A. riparium, A. subsecundum, A. trichophorum, A. trachycaulum, and A. intermedium. Bromus inermis is also a good species while Elymus junceus may do well initially but does not persist.

Onobrychis viciifolia cv. Eski and Medicago sativa cv. Spreader provide the best resistance to invasion by Salsola kali. Onobrychis viciifolia is at least comparable or better than Medicago; Eski is particularly good on dry land but has limited nitrogen fixing ability. Medicago cv. Ranger has illustrated good and poor results. Ranger is persistent and non-aggressive in grass mixes. Medicago cv. Ladak has also performed well. Astragalus cicer establishes slowly but provides good cover and erosion control, is persistent, tolerant of grazing, and has high forage quality. Lotus corniculatus is apparently not suited to minespoil revegetation in Montana.

Results of grass and legume research on the plains appear to be site specific in some instances, though probably not as much so as in mountain and northern regions.

Good site preparation is essential in plains regions (assuming productivity is of primary importance).

More research is required on species suitable for saline spoils, resistance to Salsola kali and optimum seeding times for Onobrychis vicilfolia.

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23. USE OF AGRONOMIC GRASSES AND LEGUMES IN REVEGETATION OF OTHER GEOGRAPHIC REGIONS

Agronomic species have been tested in many other less relevant areas throughout North America. While numerous factors such as climate and species reduce the applicability of this information to Alberta, some information serves to reinforce conclusions drawn from studies elsewhere. This is particularly true with respect to the ubiquity of some species.

Work in the Midwest (Packer and Aldon 1978) has tested over 75 species, many of which are not suitable for Alberta. However, some species that have done well there, as well as in the Great Plains and western states, are the legumes Medicago spp., Lotus corniculatus, Trifolium pratense, and Melilotus spp. Fast establishing grasses are Bromus spp., Dactylis glomerata, and Festuca arundinacea. Poa pratensis, Phleum sp. and Agrostis stolonifera establish slowly. Quality and yield of forage crops grown on strip mined soil has been excellent (P in forage was high compared to farm produced forage; N and protein were also high; Ca, Mg, K compared well to regular forage). Cattle raised on strip mine pasture showed the same rate of weight gain as regular farm animals. Average carrying capacity was 0.8 ha per animal; some trials showed a weight gain of 0.75 kg/day for 180 days.

Information on niches and roles in reclamation of a wide variety of grasses and legumes is presented by Bennett et al. (1978). No test data are provided but tolerances and other attributes are described for such suitable western species as Festuca arundinacea, F. rubra var. commutata, F. rubra, Agrostis stolonifera, other Agrostis species, Andropogon sp., Panicum virgatum, Bromus sp., Phleum sp., Dactylis glomerata, Lolium sp., Poa sp., Phalaris arundinacea, Medicago sp., Trifolium repens, T. pratense, and Lotus corniculatus.

Appalachia is even further removed from the Alberta scene; nevertheless, several successful species are common to both areas.

Generally, vegetation studies in Appalachia are on acid spoils and deal with amendments to control pH. Bromus inermis, Festuca arundinacea, Phleum pratense, and Dactylis glomerata all did well on

treated acid minespoil in Virginia (pH raised from 3.8 to 4.0, to 4.7 to 6.7; higher at shallow depths). However, Festuca cv. K31 and Phleum were by far the best (Jones, Armiger and Bennett 1975a). Other research indicated that Festuca arundinacea was sensitive to pH and performed best above pH 5.0 (Plass and Vogel 1973; Vogel and Berg 1968). Lotus corniculatus performs very well on acid (pH 5.4) spoil (Plass and Vogel 1973) and survived to 10°C in one study (LeRoy 1973). Secale cereale is often established as a cover crop and chemically treated to die off and provide mulch (Jones, Armiger and Bennett 1975b; Bennett 1971).

In a Nova Scotia study, coal spoil was covered with grey-brown clay loam till, seeded to grass and legumes at 56 kg/ha in June, and fertilized with 337 kg/ha of 12-24-24 plus 6.7 t/ha of limestone (Boutilier and Morton 1978). The pH was raised to 5.2 from a pre-treatment value of 4.8. Various grasses and legumes alone, and in mix, were tried and subjectively rated. Legumes, particularly Lotus corniculatus and Vicia cracca did poorly. Festuca rubra, F. elongatum, Phalaris arundinacea, and Poa compressa cv. Rubens alone or in mix were judged most suitable. Legumes improved the following year. Further tests on similar material with pH 7 showed similar good performance of the above species plus Bromus, Phleum, and Trifolium repens (Table 23.1).

Very little work done in the south-western U.S. is applicable to Alberta. One paper suggested Agropyron cristatum cv. Nordan, A. intermedium cvs. Amur and Oahe, A. riparium cv. Sodar, Melilotus officinalis cv. Madrid, and Medicago sativa cv. Rhizoma as suitable for lowland areas in the Piceance Basin, Colorado (Sims and Redente 1974). There is no definite indication that these species would perform well in Alberta, however. Kay (1973) in California advised the use of small seeded, persistant bunchgrasses which were quick to establish (Dactylis glomerata, Poa ampla, Festuca ovina cv. Durar) and bunchgrasses such as Agropyron riparium and A. smithii. All of these species produce good root growth and minimal top growth. Fertilizer (280 kg/ha 16-20-0) is recommended to maintain grasses.

Table 23.1. Mine spoil turf establishment trials, Point Aconi, Cape Breton, Nova Scotia. Plots established June 8, 1976 and recorded on October 28, 1976.

Test Variety	Grass Height In Centimeters		Rating 1 to 10 (10 best)				
	Low Fert	High Fert	General Appearance	Density	Colour	Grass Growth	Comments
1. Rubens Canada bluegrass	2.5	10	6.0	5.0	7.5	good	Uniform colour with high or low fertility
2. Tall fescue	10	25	9.0	7.0	7.5	fair	Seed stocks formed good cover
3. Reed canary grass	7.5	12.5	7.5	5.5	6.0	poor	Good cover on high fertility
4. Brome grass	2.5	10	6.0	4.5	6.5	very poor	Not as good as Reed canary
5. Creeping red fescue	2.5	15	9.0	6.5	9.5	good	Good coverage
6. Orchard grass	7.5	22.5	9.0	7.0	6.0	good	One of the better plots
7. White dutch clover	2.5	12.5	8.0	5.0	9.5	poor	Patchy
8. 50% Reed canary grass 50% Tall fescue	7.5	17.5	7.0	4.5	6.0	poor	Good growth
9. 50% Reed canary grass 50% Creeping red fescue	5	12.5	7.0	5.0	8.0	fair	Fair coverage
10. 50% White dutch clover 50% Creeping red fescue	10	15	8.5	6.5	9.0	fair	Possibilities
11. 90% Poa Trivalis 10% Kentucky bluegrass	2.5	15	6.0	5.0	7.0	fair	Deficiency symptoms
12. 90% Meadow fescue 10% Kentucky bluegrass	7.5	15	5.0	4.5	5.0	good	Deficiencies
13. 60% Timothy 20% Tall fescue 20% Common Canada blue	5	20	5.0	4.5	6.0	poor	One of poor plots

Continued

Table 23.1. Concluded.

Test Variety	Grass Height In Centimeters		Rating 1 to 10 (10 best)				
	Low Fert	High Fert	General Appearance	Density	Colour	Grass Growth	Comments
14. 50% Tall fescue 50% Creeping red fescue	7.5	20	6.0	6.0	8.0	fair	Growing well
15. 50% Canada bluegrass 50% Kentucky bluegrass	2.5	10	4.0	4.0	5.5	failure	Very poor
16. 1/3 Reed canary grass 1/3 Tall fescue 1/3 Creeping red fescue	2.5	25	6.0	5.5	7.0	good	Does well with fertility
17. 1/3 Canada bluegrass 1/3 Tall fescue 1/3 Timothy	10	17.5	3.0	3.0	4.5	fair	Poor coverage
18. 50% White dutch clover 20% Red clover 30% Alsike clover	2.5	10	6.0	5.0	8.0	good	Very short growth, patchy
19. 10% Timothy 44% Alfalfa 46% Orchard grass	5	15	5.0	6.0	4.0	good	Even coverage, try alfalfa again
20. 67% Creeping red fescue 33% Chewings fescue	2.5	7.5	6.0	4.5	6.5	good	Some deficiencies
21. 50% New Zealand bentgrass 50% Highland bentgrass	2.5	5	3.0	3.0	6.0	good	Little difference in high or low fertility

Source: Boutillier and Morton (1978)

Seeding Rates = 56 kg/ha (50 lbs/A)
High fertility = 674 kg/ha (600 lbs/A)
Low fertility = 337 kg/ha (300 lbs/A)
Soil pH = 7.0
Soil type = Clay

Growing Season mixed dry spells and generally adequate moisture.

Note: Higher seeding rate critical with low fertilizer.
Many blanks in plots with low seeding rate 22.5 kg/ha.
No blanks in high fertility areas with low seeding rate.
Phosphorus deficiency showed up in mid-September.
High seeding rate was beneficial.

On colliery spoil heaps in England Agrostis tenuis, Festuca rubra and Dactylis glomerata performed best (Richardson, Shenton and Dicker 1971). Seeding rates were high. Festuca rubra has been found to be tolerant of dry and otherwise poor conditions and high pH. On iron ore smelter wastes that were of high pH and deficient in micronutrients N and P, grasses were sown at 100 kg/ha and moderately fertilized at sowing time (N, P_2O_5 and K_2O each at 75 kg/ha followed by 125 kg/ha P_2O_5 and 100 kg/ha of N in fall and 125 kg/ha of NPK in spring). Subjective assessment rated Festuca rubra, F. ovina, F. rubra cv. Fallax, and Lolium perenne as performing well while Cynosurus cristatus, Poa pratensis, and Agrostis tenuis were rated fair to poor (Gemmell 1975).

Metal tolerant strains of F. rubra, Agrostis stolonifera and L. perenne have been selected in Great Britain for use on metal mine tailings. The tolerant species were generally lower in Pb/Zn uptake than commercial varieties but yields were not necessarily higher on all sites (Johnson, Bradshaw and Handley 1976; Smith and Bradshaw 1970).

23.1 SUMMARY

Research in other geographic areas indicated the wide adaptability of a number of species, primarily Agropyron, Festuca, Poa, Bromus, Phleum, and Dactylis glomerata. This information supports the evidence that these species would be adaptable to many, if not most situations in Alberta.

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24. USE OF INTRODUCED TREES AND SHRUBS IN REVEGETATION

24.1 NORTH-EAST (OIL SANDS) REGION

Selner and Thompson (1977) tested 24 tree and shrub species and 23 Populus clones on oil sands tailings and waste dumps in the Fort McMurray, Alberta area. Bare-root stock, container seedlings, and cuttings were tested. Trials were fertilized and various peat treatments applied to sites prior to planting. Initially Populus clones did better than other species. However, competition from grasses and legumes, rodent damage, and design considerations made interpretation of data difficult. A report is in progress which attempts to synthesize the massive amount of data for the project.

Results of studies carried out in Denmark on the Jutland Peninsula (Schlatzer 1973) are relevant to the Oil Sands region of Alberta. The climate of the Jutland area is cool coastal (sometimes continental) with high winds and late spring frosts.

Trials were carried out on sandy spoil (pH 2.5 to 5.0) with toxic Mn and Al concentrations and a low nutrient status.

It was found that most broad-leafed deciduous stock could be planted larger than conifer stock and was not as susceptible to damage by drifting sand if planted deeply. Hybrid aspen (P. tremula x P. tremuloides) and Alnus glutinosa were tested with physical protection from sand blasting. Protection was critical and boards were used in rows 20 m apart. This was found to be logistically better and cheaper than tree branches.

Hybrid Populus spp. produced suckers 10 m away in six years and were rarely damaged by frost. Sand blasting and insects were problems. Alnus glutinosa was successful but short lived (10 to 20 years) and was suggested as a good nurse crop. Provenances varied in overall performance and disease resistance.

Betula tolerated levels of pH and Mn that were toxic to other species (according to citations from other authors). Transplanting shock created some problems but subsequent performance was good.

Salix species and clones varied in performance. Amelanchier alnifolia and Sorbus aucuparia were prone to browse damage.

Schlatzer noted some unexpected tolerances in several exotic species.

Some information presented for the Plains region (below) may be relevant to the Oil Sands region.

24.2 PLAINS REGION

The only comprehensive study of revegetation of mine spoil with trees and shrubs on the Canadian plains has been carried out near Estevan, Saskatchewan (Flavelle 1974; Saskatchewan Department of Tourism and Renewable Resources, Forestry Branch 1973). Various cultivars were tested on saline spoil with pH values up to 8 or 8.5. Soil moisture and salinity were critical factors governing revegetation success.

Results from very early studies (pre-1965) on abandoned spoil indicated that the most successful species were Elaeagnus angustifolia (good survival and growth), Ulmus pumila (limited to better sites, addition of organic matter desirable), Rosa hansoni (good survival, fair to poor growth), and Pinus sylvestris (fair survival on better sites and with organic matter added). Salix species worked well on moist to wet sites (rooted stock) with S. elegantisima var. pentandra, S. alba, S. acutifolia, S. nigra and S. alba var. vittelina performing best. Recommended Populus clones were P. canadensis var. grandifolia and P. petrowskiana cvs. Griffin, Northwest, and Wheeler. The spoil on these sites (Estevan and Prince Albert) is topographically, chemically, and microclimatically quite variable. Near impounded lakes, soils were very saline but were much better a few feet up slope. On ridges and west and south facing slopes physical conditions and moisture were very poor.

As this study progressed it was recommended that old spoil be reshaped to a rolling topography to prevent a large saline area with moisture problems; topsoil should be preserved. These studies covered 1965 to 1974. Some species were planted over several years.

Tree and shrub plantings were confined to north and east-facing slopes. A narrow zone (0.5 m vertical to 1.8 m vertical) above ponds was best due to lake level fluctuation and site conditions. Successful species were:

1. Elaeagnus angustifolia: good.
2. Ulmus pumila: fair, but limited to favourable sites; addition of organic matter promotes much better survival and growth.
3. Pinus sylvestris: on higher levels (1.2 to 1.8 m) on better sites with addition of organic matter. Can be used for special planting effects, not for general planting.
4. Salix: Rooted stock should be used in moist valleys. The following varieties show best results: Salix fragiles vars. bollota and decipens, S. alba and S. alba vars. vittellina and nova, S. nigra and S. acutifolia.
5. Populus: rooted stock. The best varieties are: canadensis; grandifolia; Berolinensis; cvs. Brooks #1, Northwest, petrowskiana; and Wheeler #4. To be planted along lakes at 0.5 to 1.5 m levels.

On levelled spoils (slightly disced) Elaeagnus angustifolia, Ulmus pumila, hybrid Populus (Populus canadensis var. grandifolia; P. petrowskiana; cvs. Brooks #1; Wheeler #4; Northwest), Pinus sylvestris (on selected sites) and Rosa hansoni have performed well. These trials have been carried out only since 1971.

Trials in the northwestern Great Plains (Orr 1977) compared bare-root and container stock combined with irrigation trials. Trees were planted into an Agropyron-Stipa-Atriplex stand, at 1.8 x 2.4 m spacing, with rows clean cultivated. Spoil was of quite good quality. Fraxinus pennsylvanica and Elaeagnus angustifolia were the only species that performed well without irrigation (bare-root stock). In later trials, irrigation proved beneficial to Fraxinus pennysylvania, Prunus americana, and Caragana arborescens. Results were quite variable from year to year (Tables 24.1 to 24.3). Although several of the species

Table 24.1. Survival percentages by species bare-root dryland planting at AMAX Belle Ayr Mine, May 1973 and May 1974.

Species	Planted May 1973 Date of survey			Planted May 1974 Date of survey
	Sept. '73	June '74	Sept. '74	Sept. '74
Green ash	96 a	80	76 a	93 a
Russian olive	76 b	70	51 b	54 b
Rocky Mtn. juniper	49 c	49	39 b	45 c
Ponderosa pine	44 c	18	11 c	32 c
Buffaloberry	42 c	28	15 c	48 c
American plum	30 d	18	12 c	60 b
Siberian peashrub	16 d	12	9 c	56 b

Source: Orr (1977)
Note: Species with different letters within survey dates are significantly different at p = .05.

Table 24.2. Percentage survival by species and irrigation treatment after two years (1975 and 1976) at AMAX Belle Ayr Mine (bare-root stock).

Species	Irrigated	Not Irrigated	Percent response
Green ash	70	41	71
Russian olive	29	22	32
Rocky Mtn. juniper	2	0	--
Ponderosa pine	10	0	--
Buffaloberry	50	14	257
American plum	79	41	93
Siberian peashrub	51	36	42
Average	42	22	

Source: Orr (1977)

Table 24.3. Survival percentages by plant species, planting stock, and watering treatments at the end of the first growing season and after the following winter, AMAX Belle Ayr Mine.

Species	Planting Stock				Watering			
	Fall 1976		Spring 1977		Fall 1976		Spring 1977	
	Container	Bareroot	Container	Bareroot	Irrigated	Nonirrigated	Irrigated	Nonirrigated
Green ash	78	98	42	74	92	84	61	56
Russian olive	72	90	21	42	84	78	26	38
Rocky Mtn. juniper	97	92	76	64	97	92	89	52
Ponderosa pine	93	74	51	44	86	81	66	30
Buffaloberry	78	76	36	44	82	72	54	24
American plum	94	99	60	74	96	97	78	56
Siberian peashrub	88	86	80	81	83	92	80	81
	NS [a]		** [b]		NS		**	
Average	86	88	52	60	89	85	65	48
Species interaction	**		**		NS		**	

Source: Orr (1977)

[a] NS = difference not significant at p = .05

[b] ** = significant at p = .01

are native to Montana, they are not all native to the plains area (e.g., Juniperus scopulorum). The results suggested that consistent performance cannot be expected and may be seasonal and site specific.

Trials with bare-root deciduous trees at Colstrip, Montana, included planting of large (1.8 to 2.4 m) Populus alba, P. sargentii, Salix pentandra, S. alba var. vitteliina, Fraxinus pennsylvanica, Elaeagnus angustifolia and Ulmus pumila (DePuit, Coenenberg and Willmuth 1978). Ten trees of each were planted. After two years, survival and vigour were as shown in Table 24.4. The plastic apron was to warm the soil and preserve soil moisture (Sindelar et al. 1974). By 1976 (five years after planting) survival and vigour were as presented in Table 24.5. Some species were selectively damaged by large mammals (e.g., S. pentandra and S. alba var. vitteliina were browsed). Fraxinus pennsylvanica, E. angustifolia, and U. pumila continued to perform relatively well.

Thornburg and Fuchs (1978) provide a list of shrubs for use in dry regions. Careful management is required for successful reclamation with shrubs in these areas.

McArthur, Giunta and Plummer (1974) pointed out the great opportunities to improve shrubs by selection of ecotypes and genetic experimentation. A table of native and introduced species (Table 24.6) is presented showing values for range restoration and soil stabilization.

24.3 MOUNTAINS AND FOOTHILLS REGION

No studies were found that provided any information relevant to Alberta on introduced species for montane or alpine areas. While research would provide benefits, native species are probably of greater importance in this region.

24.4 OTHER GEOGRAPHIC REGIONS

Literature reviewed and included in this section may have applicability to Plains and Oil Sands regions of Alberta.

Table 24.4. Survival and vigour of 70 deciduous trees on mine spoils at Rosebud Mine, Colstrip, Montana. (21 August 1975).

	Plastic Apron		Control		Total
	Survival	Vigour	Survival	Vigour	Survival
Native green ash	100%	poor	100%	good	100%
Russian olive	100%	good	100%	good	100%
Siberian elm	100%	fair	80%	fair	90%
Silver poplar	80%	poor	20%	poor	50%
Cottonwood	100%	fair	40%	poor	70%
Golden willow	100%	good	80%	poor	90%
Laurel willow	40%	poor	40%	poor	40%

Source: Sindelar et al. (1974).

Table 24.5. Survival and vigour[a] of 70 deciduous and 8 ponderosa pine trees on mine spoils at Rosebud Mine, Colstrip, Montana. (12 August 1976).

	Plastic Apron		Control		Total
	Survival	Vigour	Survival	Vigour	Survival
Laurel willow	0	-	0	-	0
Golden willow	40%	Fair	20%	Fair	30%
Cottonwood	40%	Fair	0	-	20%
Silver poplar	40%	Fair	20%	Fair	30%
Native green ash	100%	Good	40%	Fair	70%
Russian olive	100%	Fair	100%	Fair	100%
Siberian Elm	100%	Fair	80%	Fair	90%
Ponderosa Pine			37.5%	Fair	37.5%

Source: DePuit, Coenenberg and Willmuth (1978).
[a] Vigour evaluated using a qualitative rating system.

Table 24.6. Shrubs useful for range restoration and soil stabilization.

Species	Value for: Range Restoration	Value for: Soil Stabilization	Adaption[a] to vegetal types
Apache-plume (*Fallugia paradoxa*)	Medium	High	JP, BB, BS, MB
Bitterbrush, antelope (*Purshia tridentata*)	High	High	JP, MB, BS, BB
Bitterbrush, desert (*Purshia glandulosa*)	Medium	High	JP, BS, BB, MB
Bladdersenna, common[b] (*Colutea arborescens*)	Low	High	MB, JP, A
Ceanothus, martin (*Ceanothus martinii*)	Medium	High	MB, JP, A, BS
Chokecherry, black (*Prunus virginiana*)	Medium	High	MB, JP, A, BS, SA
Cherry, Bessey (*Prunus besseyi*)	Low	High	MB, JP, A
Currant, golden (*Ribes aureum*)	Medium	Low	MB, JP, BS, WM
Elder, blueberry (*Sambucus cerulea*)	High	High	MB, JP, A, BS
Honeysuckle, tatarian[b] (*Lonicera tatarica*)	Medium	High	MB, JP, BS
Kochia, prostrate[b] (*Kochia prostrata*)	High	High	BS, Bg, SS, IS
Lilac, common[b] (*Syringa vulgaris*)	Medium	High	MB, JP, BS, A
Mahogany, birchleaf (*Cercocarpus montanus*)	Medium	High	JP, MB, BS

continued ...

Table 24.6. Continued.

Mahogany, curlleaf (Cercocarpus ledifollius)	Medium	High	MB, JP, P
Maple, bigtooth (Acer grandidentatum)	Medium	High	MB, A, JP
Oak gambel (Quercus gambelii)	Medium	High	MB, JP, A
Peachbush, desert (Prunus fasciculata)	Low	High	JP, MB, BS, SS BB
Peashrub, Siberian[b] (Caragana arborescens)	Low	Mediam	MB, JP, BS
Rabbitbrush, low (Chrysothamnus viscidiflorus)	Medium	High	BS, SS, JP, MB A
Rabbitbrush, rubber (Chrysothamnus nauseosus)	Medium	High	BS, JP, MB, A, BG
Rose, woods (Rosa woodsii tridentata)	Medium	High	MB, JP, A, BS
Sagebrush, big (Artemisia tridentata)	High	High	BS, JP, MB, A, SA
Sagebrush, black (Artemisia nova)	High	High	JP, BS, BB, SS
Sagebrush, Bigelaw (Artemisia frigida)	Medium	High	JP, BS, BB, SS
Sagebrush, fringed (Artemisia frigida)	Medium	High	BS, JP, BG, SS A
Sagebrush, sand (Artemisia follifolia)	Medium	High	BB, SD, BS, JP
Saltbush, fourwing (Atriplex canescens)	High	High	BS, JP, SS, BB SD
Serviceberry, Saskatoon (Amelanchier alnifolia)	Medium	Medium	MB, JP, BS
Serviceberry, Utah (Amelanchier utahensis)	Medium	Medium	JP, MB, BS

continued ...

Table 24.6. Concluded.

Snowberry, mountain (*Symphoricarpos oreophilus*)	Medium	High	JP, BS, BB
Sumac, skunkbush (*Rhus trilobata*)	Low	High	JP, MB, BS, SD
Sumac, Rocky Mountain (*Rhus glabra cismontana*)	Low	High	JP, MB, SS
Winterfat (*Eurotia lanata*)	High	High	JP, SS, BS, BG MB
Wormwood, oldman[b] (*Artemisia abrotanum*)	Low	High	MB, JP, A, SA

Source: McArthur, Giunta and Plummer (1974).

Note: MB = Mountain brush; BG = Black greasewood; JP = Juniper-pinyon; AA = Arctic alpine; SA = Subalpine; SD = Sand dune

[a] These symbols are listed in decreasing order of species adaptation to vegetal types.

[b] Exotic, introduced shrubs.

Many studies have dealt with shrubs for use in reclamation in the eastern United States. However, most species that tend to do well there are of little use in Alberta. As well, spoils in the eastern States tend to be acid. Pinus sylvestris has been used on a diversity of spoils. Care must be taken to select the correct provenance. Alnus glutinosa has performed very well on low pH spoil. Hybrid Populus have been used extensively; clones differ greatly in performance. Fraxinus pennsylvanica performed poorly (Wheeler 1965).

Tests of 60 clones of hybrid Populus in Pennsylvania (unrooted cuttings 30 cm long, and 0.6 to 1.3 cm diameter) resulted in selection of 13 promising clones for reclamation (Davis 1964). Height growth and survival increased with pH above 3.1.

Czapowskyj (1970) tested various species of trees on mine spoils in Pennsylvania. Results for species possibly useful in Alberta (Table 24.7) and spoil characteristics (Table 24.8) are given. These are somewhat in conflict with the work by Geyer (1971, 1972a,b, 1973) and Geyer and Rogers (1972) who have shown growth of many trees to be inhibited by grading.

Studies of trees and shrubs on metallic mine tailings in Michigan (Shetron and Carroll 1977) showed hybrid Populus and Alnus glutinosa to be quite successful after five years.

In Great Britain spoil heaps of shale, sandstone, and coal have been successfully planted to Alnus incana and A. glutinosa (Jobling 1974; Richardson, Shenton and Dicker 1971).

24.5 SUMMARY

Information available from the reclamation literature is of limited value to the Oil Sands region. Populus and Salix species and clones have received most attention and appear to be suitable for reclamation in the Region.

Considerable research is required on optimum species, propagation, establishment, and maintenance (fertilizers, control of rodent damage, establishment into grass swards). A well-designed program to address these needs is currently underway.

Table 24.7. Average survival (%) after five years of forest trees planted on anthracite strip-mine spoils, Pennsylvania.

Species	Spoil Type									
	I		II		III		IV		Average	
	G[a]	U	G	U	G	U	G	U	G	U
Hybrid poplar	90	85	78	55	97	57	12	24	77	55
European alder	83	70	69	51	85	40	31	14	68	41
Jack pine	75	46	96	84	97	33	72	13	85	44
Scotch pine	70	32	86	88	82	38	56	12	74	42
Norway spruce	48	12	32	34	65	32	20	1	41	20
White spruce	54	15	27	52	51	28	10	4	36	25

Source: Czapowskyj (1970).

[a] G = Graded
U = Ungraded

Table 24.8. Selected chemical characteristics of experimental sites in Pennsylvania (average of eight replications).

Spoil type	Grading conditions	Reaction	Extractable	Total	Milliequivalents of "soil" fraction					
					Exchangeable bases			Cation exchange capacity	Ca + Mg + K	
					Ca	Mg	K		Total	Saturation
		pH	P ppm	N Pct.						Pct.
I	Graded	5.7	27.4	0.13	29.3	4.3	1.9	63.0	35.5	56
	Ungraded	4.5	59.8	0.14	8.6	3.5	1.4	119.0	13.5	11
II	Graded	4.8	50.1	0.07	23.4	4.1	2.2	119.3	29.7	25
	Ungraded	4.6	26.3	0.15	9.0	4.8	1.7	67.0	15.3	23
III	Graded	6.3	41.9	0.10	28.5	3.2	2.2	61.0	33.9	56
	Ungraded	4.2	37.7	0.09	4.6	2.8	1.2	57.0	8.6	15
IV	Graded	7.1	64.2	0.07	23.6	3.5	3.3	40.0	30.4	76
	Ungraded	7.5	65.6	0.08	28.1	3.4	2.4	37.0	33.9	92

Source: Adapted from Czapowskyj (1970)

In the Canadian plains, the number of shrub species tested has not been extensive. No well designed studies relating performance to site and other environmental variables were encountered. Shrubs and trees must be selectively located in relation to site. Moisture and chemical characteristics (i.e., salinity) are critical to establishment and survival.

Elaeagnus angustifolia has performed consistently well on plains mine sites, as has Fraxinus pennsylvanica and Rosa hansoni. Salix (rooted stock) and Populus (several varieties) have performed well on moist to fresh sites. Ulmus pumila has performed well on better quality sites. Pinus sylvestris is not recommended for general planting but may be used on dry sites for special effects. Prunus americana and Caragana arborescens have performed well with irrigation.

Special cultural treatments (cultivation, irrigation, container planting) are beneficial and will improve the success of some species. The reader is referred to those sections of this report. Management is particularly critical in dry areas.

No literature was encountered that evaluated non-native shrubs and trees in mountainous regions.

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SECTION VIII

USE OF NATIVE SPECIES IN RECLAMATION

Work on native species in Alberta has been carried on from three main centres; the University of Alberta, Alberta Agriculture (later Vaartnou and Sons) and Alberta Forest Service.

The work of Vaartnou is probably the earliest, beginning about 1973. Early work surveyed and compared native vegetation on disturbed and undisturbed areas near Fort McMurray, on pipelines, powerlines and roadsides. The reports attempted to describe relationships between vegetation, soils, and climate. Eighty-five useful reclamation species were described: 44 grasses, 19 legumes, and 22 shrub species (Vaartnou and Wheeler 1974).

The Alberta Forest Service studies have been carried out primarily on foothills and mountain sites. University of Alberta studies (Walker, Sadasivaiah, and Weijer 1977; Walker and Weijer 1974, 1975) were carried out on the University Farm at Ellerslie, Alberta and in the field, and were related to revegetation of subalpine and alpine sites in the Rocky Mountains from Cadomin to Grande Cache, Alberta.

Our knowledge of native trees and shrubs is extremely limited. Considerable work has been done on propagation techniques, particularly methods of achieving seed germination, and work in this area continues on several fronts. However, very little is known about methods of establishment. A source of information exists in forestry literature with respect to commerical conifer and hardwood tree species. However, shrubs are the preferred woody vegetation on many spoils in the west. Comparisons of bare-root versus container stock, hardwood versus softwood, and rooted versus unrooted cuttings may be found in the literature but information is limited. We know very little about optimum time for collecting and planting cuttings, optimum container sizes for shrubs, and virtually nothing about the genetic variability of shrubs. McArthur, Giunta and Plummer (1974) pointed out the opportunities to improve shrubs by selection of ecotype and genetic experimentation. However, in many cases time is a limiting factor and one must use material at hand.

25. USE OF NATIVE GRASSES AND FORBS IN REVEGETATION OF THE NORTH-EAST (OIL SANDS) REGION

There are no studies on use of native grass and legume species that are specific to the Oil Sands region. However, studies were carried out in that area and reported on in combination with studies from several other areas by Vaartnou and Sons Enterprises Ltd. (1977a,b, 1978), Vaartnou ed. (1976), Vaartnou (1976), Vaartnou and Wheeler (1974, 1975).

Early work by scientists working with Vaartnou ed. (1976) looked at growth of native species under controlled conditions (Warrington 1976). Hedysarum alpinum, Lathyrus venosus and Vicia cracca were grown in growth chambers with 14-14-14 fertilizer applied at 800 kg/ha. Eight types of soil from disturbed areas were tested. All soils were low to very low in N and P, and oil sands tailings and tar sands were also low in K. Fertilization had very little effect on root length but did increase root weight. No statistical analysis was done. Effects on nodulation were inconclusive.

Yamanaka (1976) tested several species of grasses on the same soils. Combined biomass was measured for ten species tested on four soils. Fertilizer greatly increased top and root biomass but again statistical analysis was not done.

The work of Vaartnou covered many areas, soils, and species. The amount of data produced was voluminous and not fully summarized. The clarity of the experimental design varied, as did the amount of background information presented (conditions at time of planting, etc.). The material contains considerable valuable information but it is difficult to interpret in the present form. The reader will have to review original reports and summarize information on individual species as he sees fit, until the reports can be condensed to a more succinct form.

Roadside plots established by Vaartnou were evaluated and reported on by Wheeler and Yarish (1978). In most cases, the plots were overwhelmed by the cultivar cover crop; native grass and legume ecotypes could not be found. The authors noted showy and late Oxytropis sp. at

Grande Cache, Agropyron smithii at Onefour, and Festuca ovina in the south-eastern part of the province as exceptions. The ability of the latter species to survive and its low growth form suggests it is a good roadside species where tall growth is undesirable.

Elymus giganteus was found by Schwendiman (1977) to be a very suitable species for dune control in inland Washington (precipitation zone--19 cm; warm summers; mean annual evaporation--121 cm). Four fertilizations (N) plus 10 irrigations were required. This is obviously a specialty treatment and the reader should consult the original article for details of methodology and costs.

25.1 SUMMARY

Data on native grasses and legumes in the North-east region is inconclusive. Very little work has been done and there is a distinct need for research.

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26. USE OF NATIVE GRASSES AND FORBS IN REVEGETATION OF THE MOUNTAINS AND FOOTHILLS REGION

Selner and King (1977) studied native species at nine locations in the eastern slopes of Alberta, including mainly open pit mining and coal exploration sites at high elevation. Containerized seedlings were hardened at the nursery and outplanted in July and early August. Only preliminary information was available. First year survival ranged from 67 to 100% on undisturbed sites and 64 to 100% on disturbed sites. Festuca saximontana was lowest on undisturbed and Stipa columbiana lowest on disturbed sites. Seed production by species is given in Table 26.1.

An excellent, well designed study (Takyi and Russell 1980) is being carried out at an abandoned coal mine site near Cadomin, Alberta (elevation 1675 m; tree line is between 1980 and 2100 m). Overburden is strongly alkaline (pH approximately 9), non-saline coarse material with low moisture retention capacity and low cation exchange capacity. The material is low in N, and very low in P, but has adequate K. Top-dressing was non-saline (pH 6.5 to 6.9), of moderate texture with 44% silt and clay. The material had adequate K but was very low in N and low to medium in P. Fertilizer was added to give 30 kg N, 30 kg P and 25 kg K per hectare for adaptability trials and 40-20-13 or 80-40-25 kg/ha of NPK, respectively, for seed mix experiments.

After two seasons, the wheatgrasses (Agropyron dasystachyum, A. subsecundum, and A. trachycaulum) provided the best cover. Other species cover was generally less than 15% (Table 26.2). The same wheatgrasses, along with Poa interior, had good to excellent seed production (Table 26.3). Topsoiling effect was greater on seed production than on cover but varied considerably with species. More time is required before this experiment can be fully evaluated.

The work of Walker, Weijer and Sadasivaiah is among the most important native plant work in Alberta (Sadasivaiah and Weijer 1980; Sadasivaiah, Walker and Weijer 1979, Walker, Sadasivaiah and Weijer 1977; Walker and Weijer 1974, 1975). This is a plant selection experiment that began in 1974. A number of plants were selected for

Table 26.1. Seed production for native grass adaptability trials at high elevation sites in Alberta.

Genus and Species	Surviving Plants Producing Seed(%)		Avg. No. of Seed Heads Per Seed-Producing Plant	
	Undisturbed	Disturbed	Undisturbed	Disturbed
Agropyron dasystachyum	4	22[a]	1.3	1.5
Deschampsia caespitosa	86	71	2.8	3.6
Festuca saximontana	57	100	3.2	8.0
Poa alpina (1)	64	74	2.8	4.7
Poa alpina (2)	90	77	2.8	4.2
Stipa columbiana	11	19	1.0	1.3
Trisetum spicatum	61	63	2.3	4.9

Source: Selner and King (1977).

[a] Underlined values are not significantly different based on t-Test at the 10% level.

Table 26.2. Percent cover after two years of native and two cultivated species seeded at Cadomin, Alberta.

Species	Raw Overburden % Cover[a]	Overburden Topdressed With Soil
Agropyron dasystachyum	27.6 f	26.1 e
Agropyron subsecundum	11.9 cde	20.9 de
Agropyron trachycaulum	27.3 f	20.5 de
Agropyron trachycaulum 'Revenue' (check)	15.9 e	15.0 cd
Calamagrostis purpurascens	1.5 ab	4.1 ab
Festuca saximontana	9.3 bcde	4.1 ab
Koeleria cristata	6.0 abcd	4.1 ab
Phleum alpinum	5.0 abc	8.1 abc
Poa interior	0.8 a	3.0 ab
Stipa columbiana	2.4 ab	0.6 a
Trisetum spicatum	2.3 ab	7.2 abc
Deschampsia caespitosa	3.9 abc	10.0 bc
Festuca idahoensis	4.1 abc	2.6 ab
Festuca rubra	7.9 abcde	14.5 cd
Festuca rubra 'Boreal' (check)	14.0 de	21.2 de

Source: Takyi and Russell (1980).

[a] Means in each column followed by a common letter are not significantly different at the 5 percent level (Duncan's Multiple-Range Test).

Table 26.3. Seed production ratings of native and two cultivated grasses, Cadomin, Alberta.

Species	Seed Production	
	Raw Overburden	Overburden Topdressed With Soil
Agropyron dasystachyum	3	4
Agropyron subsecundum	2	3
Agropyron trachycaulum	3	3
Agropyron trachycaulum cv. Revenue (check)	4	4
Calamagrostis purpurascens	1	2
Festuca saximontana	2	2
Koeleria cristata	1	2
Phleum alpinum	1	2
Poa interior	3	3
Stipa columbiana	0	1
Trisetum spicatum	1	3
Deschampsia caespitosa	0	2
Festuca idahoensis	0	0
Festuca rubra	0	1
Festuca rubra cv. Boreal (check)	1	3

Source: Adapted from Takyi and Russell (1980).

Ratings: 0 = no seed production
1 = very poor to poor seed production
2 = fair seed production
3 = good seed production
4 = excellent seed production

high elevation alpine and sub-alpine sites, and work concentrated primarily on Agropyron spp. Plants were collected from many sites in the Rocky Mountains and transplanted at the University of Alberta farm at Ellerslie. Each year the best performers, in terms of disease resistance, tolerance to stressful environmental factors, and seed yield, were selected and seed harvested for further selection. Plants were grown and transplanted back to environments in the mountains. Performance there was also used as a selection criterion. Grasses and legumes selected are shown in Table 26.4 (Walker, Sadasivaiah and Weijer 1977).

The study looked at germination, mode of establishment and shattering behaviour. Poa interior was studied for apomyxis, a useful method of obtaining pure lines of species. Moisture contents at which seed heads shatter is typically broad, ranging from 15 to 40% within each of 13 species.

Container grown seedlings of 13 species outplanted to mountain sites have averaged 80% survival and 51% flowering. Plants do not seem to exhibit photoperiodic response to flowering (within the area planted) and seem to be broadly adapted to Alberta's Rocky Mountain sites. Superior species were Poa alpina, P. interior, Festuca saximontana, Trisetum spicatum, and Agropyron latiglume.

Agropyron dasystachyum, A. trachycaulum, A. subsecundum, and Koeleria cristata appear to be excellent for sites below the treeline.

Three species, (Agropyron trachycaulum, A. dasystachyum, and A. subsecundum) are currently in the final testing stage prior to application for licensing.

Other species (Deschampsia caespitosa, Poa alpina, P. interior, Festuca saximontana, and Trisetum spicatum) have indicated good performance under alpine conditions and have been incorporated into the selection program.

Work was carried out by Vaartnou for Parks Canada in Jasper National Park and later evaluated by Harrison (1980). Results were difficult to interpret. Legumes (Hedysarum mackenzii, H. alpinum, and Astragalus sp.) did not establish well from seed. Subjective analysis

Table 26.4. Grass and legume species collections obtained for mass selection program, University of Alberta.

Species	Number of Accessions
GRASSES	
Agropyron spicatum	6
Agropyron dasystachyum	16
including albicans	
riparium	
griffithsii	
Agropyron trachycaulum	20
including subsecundum	
latiglume	
Agrostis scabra	2
Bromus pumpellianus	8
Calamagrostis canadensis	1
C. purpurascens	7
C. inexpansa	1
Danthonia parryi	2
D. intermedia	3
Deschampsia atropurpurea	3
D. caespitosa	2
Elymus canadensis	1
E. innovatus	6
E. cinereus	1
Festuca scabrella	11
F. idahoensis	7
F. ovina	12
Helictotrichon hookeri	4
Koeleria cristata	14
Oryzopsis hymenoides	1
Phleum alpinum	8

continued ...

Table 26.4. Concluded.

Species	Number of Accessions
Poa alpina	18
P. arctica	2
P. cusickii	2
Schizachne purpurascens	1
Stipa comata	2
S. spartea curtiseta	2
S. columbiana	6
S. viridula	2
S. richardsonii	4
Trisetum spicatum	12
LEGUMES	
Hedysarum alpinum	2
H. Mackenzii	1
H. sulphurescens	1
Lathyrus ochroleucus	1
Vicia americana	1
Oxytropis campestris	1
Lupinus argenteus	1

Source: Walker, Sadasivaiah and Weijer (1977).

Note: Total no. of plants at Genetics Field Laboratory, Ellerslie: 25 000. Collector: David Walker

only of species was given in the review. The best performing grasses were Agropyron pauciflorum, A. trachycaulum, A. smithii and Poa pratensis (introduced). Other species varied in performance, which seemed dependent on amendments. Agropyron pauciflorum, A. riparium, A. smithii and Festuca saximontana had good early emergence. Mixtures seemed to affect development of individual species differently, depending upon species dominance in mixtures, which varied with amendments. Fertilization was important for initial establishment of plants. Unfortunately, not enough detail of treatments was given to provide sound conclusions.

Brown et al. (1976) have done excellent work on the Beartooth Plateau in Montana. Of the 200 alpine vascular plants on the plateau, only about 10% are active colonizers of disturbances and less than half of these are active universal native species found on virtually all disturbances of more than a few years of age. These include Deschampsia caespitosa, Carex paysonia, Poa alpina, Trisetum spicatum, Agropyron scribneri, and Phleum alpinum. Forbs were relatively unimportant and invaded only on mesic alkaline sites. Later reports (Brown and Johnston 1978b) from this same work listed 17 grasses and forbs that appear to be adapted for reclamation (Table 26.5).

Work in the Beartooth took place on Iron Mountain, where spoil tended to be relatively young and weakly acid (pH 5.5 to 6.5), and on the McLaren mine site which is more acid (pH 3.5 to 5.1 with extremes of 1.8). After one year on the McLaren site (Brown and Johnston 1978a) Deschampsia caespitosa, Poa alpina, Agropyron trachycaulum, and Phleum alpinum provided most of the cover. These species, plus Agropyron scribneri, are suggested to have the greatest potential for alpine revegetation. Other species such as Carex and Trisetum may be important but certain physiological limitations are not yet clearly understood. Tables 26.6 to 26.8 give first year results of seeding and planting native stock.

A preliminary study in British Columbia by Campbell and Scotter (1975) tested several species as recolonizers of trampled areas

Table 26.5. Some native plant species that appear to be best adapted to seeding and transplanting in alpine regions.

Scientific Name	Common Name
Agropyron caninum	wheatgrass
Agropyron scribneri	scribner wheatgrass
Antennaria alpina	alpine pussytoes
Carex nigricans	carex
Carex paysonis	carex
Deschampsia caespitosa	tufted hairgrass
Draba spp.	draba
Epilobium alpinum	alpine willow weed
Festuca ovina var. brachyphylla	alpine fescue
Juncus drummondii	drummond rush
Luzula spicata	spike woodrush
Phleum alpinum	alpine timothy
Poa alpina	alpine bluegrass
Polygonum bistortoides	American bistort
Salix nivalis	snow willow
Sibbaldia procumbens	sibbaldia
Trisetum spicatum	spike trisetum

Source: Brown and Johnston (1978b).

Table 26.6. Summary of first-year results of seeded demonstration area on McLaren Mine, Beartooth Plateau, Montana.

Species[a]	1976 Seeding rate kg/ha	1977 No. plants per m^2	1977 Plant Frequency
Agropyron scribneri	1.6	0	0
A. trachycaulum	8.6	26	0.83
Carex drummondii	7.8	0	0
Deschampsia caespitosa	45.2	279	1.00
Phleum alpinum	5.2	14	0.43
Poa alpina	12.7	72	0.85
Trisetum spicatum	1.9	0	0
Triticum aestivum	0	4	0.19
Weeds	0	4	0.39
Total	83.0	399	

[a] Source: Brown and Johnston (1978a).
Average production 113 kg/ha
Total cover 71.0 percent
Average plant cover 21.7 percent
Average litter cover 49.3 percent

Table 26.7. Summary of first-year results of transplant survival and production on the McLaren Mine.

Native Species	No. Planted 1976	No. Live 1977	Percent Survival	Avg. dry wt. per plant (gm)
Agropyron scribneri	8	8	100	2.0
A. trachycaulum	124	103	83	1.4
Deschampsia caespitosa	993	711	72	2.4
Phleum alpinum	1016	739	73	3.5
Poa alpina	1682	1351	80	3.7
Trisetum spicatum	86	21	24	0.9
Total/Average	3909	2933	75	2.3

Source: Brown and Johnston (1978a).

Table 26.8. Summary of first-year results of transplant growth and development on the McLaren Mine, Montana. The average basal diameter for all species at the time of planting was 2 cm.

Species	Mulch			No mulch		
	Basal Diameter cm	Plant height cm	Flower %	Basal diameter cm	Plant height cm	Flower %
NATIVES						
Agropyron scribneri	ND	ND	ND	ND	ND	ND
A. trachycaulum	1.5	12.0	0	2.1	19.3	37
Deschampsia caespitosa	2.7	8.9	0	4.4	9.4	0
Phleum alpinum	3.9	14.6	9	4.6	26.2	76
Poa alpina	4.0	7.6	0	4.8	14.7	40
Trisetum spicatum	1.5	6.0	0	4.0	6.5	0
Average	2.7	9.8	2	3.9	17.4	31
INTRODUCED						
Alopecurus pratensis	2.3	18.8	25	2.8	19.9	43
Bromus inermis	1.1	12.4	0	1.9	22.0	60
Dactylis glomerata	0.6	8.5	0	1.2	11.7	0
Festuca arundinacea	0.5	9.0	0	1.9	22.6	40
Phleum pratense	1.2	14.6	20	2.2	19.5	30
Poa compressa	5.2	33.0	100	6.0	34.0	100
Average	1.8	16.1	24	2.7	21.6	46
Average all species	2.2	13.2	14	3.3	18.7	39

Source: Brown and Johnston (1978)

at high elevation in Mt. Revelstoke National Park. Anemone occidentalis, Antennaria lanata, Arnica mollis, Carex spectabilis, Castilleja rhexifolia, Juncus drummondii, Luzula glabrata, and Valeriana sitchensis were all in good condition and should be considered as candidates for revegetation programs.

Controlled trampling studies were carried out on several vegetation communities. The ranking from most to least fragile was: Valeriana sitchensis, Vaccinium membranaceum, Cassiope mertensiana, Luetkea pectinata, and Carex nigricans.

Willard and Marr (1971) examined damage and recovery of alpine tundra areas (Kobresia myosuroides stands). After one year of trampling, the system recovered quite well. After 26 years of trampling K. myosuroides had reduced vigour, and microclimatic environments were more severe. After 38 years of trampling no recovery was indicated after two years of protection. The authors concluded that the K. myosuroides meadow was very resistant to disturbance because of strong turf, but once the turf was broken, damage to soil horizons (erosion) took place and recovery was slow.

Native species sown in mixture on fairly acid (pH 3.5 to 5.1) overburden at approximately 2500 m in Idaho were not compared individually and were treated with mulches, irrigation, top-dressing, and fertilizer. Species which appeared to dominate were Sitanion hystrix, Achillea millefolium and Bromus tectorum (Farmer, Richardson and Brown 1976).

The reader is urged to consult Grasses and Legumes for Soil Conservation in the Pacific Northwest and Great Basin States (Hafenrichter 1968). The publication summarizes 32 years of systematic testing of grasses and legumes for conservation in the intermountain west and adjacent areas of the North Pacific Coast and Great Basin. The summary is divided into 10 sections:

1. rapid-developing, short lived grasses;
2. rapid-developing, long-lived grasses for subhumid and irrigated areas;
3. saline- and alkali-tolerant grasses;
4. drought-tolerant, long-lived bunch grasses;
5. drought-tolerant, long-lived sod grasses;

6. the bluegrasses;
7. fine-leaved grasses for cover, erosion control, watershed structures, and recreation areas;
8. wet meadowland grasses;
9. grasses for dunes and sandy land; and
10. legumes.

In addition an appendix provides average seed characteristics and standards for some grasses and legumes (Table 26.9).

As with introduced species, numerous Arctic and Alaskan studies have been carried out and are considered relevant to high elevation reclamation in Alberta.

Wein and MacLean (1973) collected and tested Eriophorum vaginatum from sites in Alaska, the Yukon and Northwest Territories, and Scotland; best yields were found on disturbed areas such as burns. Seed collected within two weeks of initial seed dispersion had the highest germination. Temperatures of 25 to 30°C produced maximum germination; light treatment enhanced germination but was not required. Loss of viability during storage under room conditions was high for the first 10 months, but 28 to 52% of the seed remained viable at 19 months.

Bell (1975) tested germination of some native grasses and forbs from Inuvik and King Christian Island. Results are shown in Tables 26.10 and 26.11.

Mitchell (1973a) presented an overview (no data) of the performance on disturbed boreal and tundra sites of native and introduced species belonging to thirteen genera. In the boreal area, mesic sites are highly favourable to many species of all genera. On wetter, acidic "peaty" sites Alopecurus, Festuca, and Phleum species did well while Agropyron, Elymus, Bromus and Puccinellia did poorly. On dry sites Bromus, Festuca, Alopecurus, some Agropyron, and one Elymus performed satisfactorily.

Mitchell (1978) also reported on studies initiated at Prudhoe Bay in the Arctic between 1969 and 1971. Several native grasses were found to perform well: Poa glauca cv. Tundra; Arctagrostis latifolia cv. Alyeska; Deschampsia beringensis; Calamogrostis canadensis cv.

Table 26.9. Average seed characteristics and standards for some grasses and legumes used in the Pacific Northwest and Great Basin States.

Common name	Scientific name	Variety	Seeds per kg	Seeds per metre square at 1.1 kg/ha[a]	Seed quality standards	
					Purity	Germination
			Thousands	Number	Percent	Percent
Beachgrass						
American*	*Ammophila breviligulata*					
European*	*Ammophila arenaria*					
Bentgrass						
colonial	*Agrostis tenuis*	Astoria, Highland	18 743	2 099	95	85
creeping	*Agrostis palustris*	Seaside	17 199	1 938	95	85
redtop	*Agrostis alba*	---	11 025	1 292	90	85
Bluegrass						
alkali	*Poa juncifolia*	---	2 205	248	85	69
big	*Poa ampla*	Sherman	2 022	226	90	70
bulbous	*Poa bulbosa*	P-4874[b]	992	108	95	85
Canada	*Poa compressa*	---	5 513	614	90	NR
Canby	*Poa canbyi*	P-851	2 042	226	95	NR
glaucantha upland	*Poa glaucantha*	Draylar	5 513	646	90	75
Kentucky	*Poa pratensis*	---	4 754	538	90	75
Nevada	*Poa nevadensis*	---	2 386	269	85	65
Sandberg	*Poa secunda*	---	2 040	226	90	NR
Brome						
Alaska	*Bromus sitchensis*	---	130	15	95	85
meadow	*Bromus biebersteinii*	Regar	176	19	95	85
meadow	*Bromus erectus*	---	157	17	95	NR
meadow	*Bromus riparius*	---	157	17	95	NR
mountain	*Bromus marginatus*	Bromar	199	17	90	85
rescue	*Bromus catharticus*	---	137	15	95	85
Russian	*Bromus tomentellus*	---	247	27	92	85
smooth	*Bromus inermis*	Manchar	276	31	92	NR
Canarygrass						
reed	*Phalaris arundinacea*	---	1 116	129	96	80
Fescue						
chewings	*Festuca rubra commutata*	---	1 356	151	98	NR
hard	*Festuca ovina duriuscula*	Durar	1 246	140	95	NR
Idaho	*Festuca idahoensis*	---	992	108	90	80
red	*Festuca rubra*	Clatsop	1 356	151	98	80
sheep	*Festuca ovina*	P-274	1 499	172	95	NR
tall	*Festuca arundinacea*	Alta	507	57	98	NR
tall	*Festuca arundinacea*	Goar	399	46	98	NR
Foxtail						
creeping	*Alopecurus arundinaceus*	Garrison	1 985	226	80	80
meadow	*Alopecurus pratensis*	---	1 985	226	80	NR
Harding grass	*Phalaris tuberosa stenoptera*	---	765	86	96	75
Oatgrass						
tall	*Arrhenatherum elatius*	Tualatin	331	37	90	NR
Orchardgrass	*Dactylis glomerata*	Latar, Pomar	1 191	129	90	80
Ricegrass						
Indian	*Oryzopsis hymenoides*	P-2575	518	58	95	NR
Ryegrass						
Italian	*Lolium multiflorum*	---	479	54	95	90
perennial	*Lolium perenne*	---	545	61	98	90
Sacaton						
alkali	*Sporobolus airoides*	---	3 859	431	98	NR
Timothy	*Phleum pratense*	Climax, Drummond	2 867	323	97	80

Continued

Table 26.9. Concluded.

Common name	Scientific name	Variety	Seeds per kg	Seeds per metre square at 1.1 kg/ha [a]	Seed quality standards	
					Purity	Germination
			Thousands	Number	Percent	Percent
Wheatgrass						
bearded	*Agropyron subsecundum*	---	331	38	95	95
bluebunch	*Agropyron spicatum*	P-739	309	34	90	85
beardless	*Agropyron inerme*	Whitmar	298	32	90	85
crested	*Agropyron cristatum*	Fairway	441	50	95	85
crested, standard	*Agropyron desertorum*	Nordan	386	43	95	85
intermediate	*Agropyron intermedium*	Greenar	221	24	95	82
intermediate (dwarf)	*Agropyron intermedium*	P-14	254	29	90	90
pubescent	*Agropyron trichophorum*	Topar, Luna	201	22	90	85
Siberian	*Agropyron sibiricum*	P-27	551	61	95	85
slender	*Agropyron trachycaulum*	Primar	353	40	90	85
streambank	*Agropyron riparium*	Sodar	375	42	90	80
tall	*Agropyron elongatum*	Alkar, Largo	174	19	95	85
thick spike	*Agropyron daasystachyum*	P-1822	344	39	85	88
western	*Agrophryon smithii*	---	243	27	85	60
Wildrye						
basin	*Elymus cinereus*	P-5797	364	41	80	85
blue	*Elymus glaucus*	---	289	33	80	85
mammoth	*Elymus giganteus*	Volga	121	14	80	85
Russian	*Elymus junceus*	Vinall	375	42	90	80
Alfalfa	*Medicago sativa*	---	496	56	99	85
Clover						
alsike	*Trifolium hybridum*	---	1 504	172	96	90
Ladino	*Trifolium repens latum*	---	1 764	194	99	95
red	*Trifolium pratense*	---	620	70	96	90
subterranean	*Trifolium subterraneum*	Mt. Barker	165	18	99	90
subterranean	*Trifolium subterraneum*	Nangeela	132	15	97	80
subterranean	*Trifolium subterraneum*	Tallarook	115	13	99	90
white	*Trifolium repens*	New Zealand	1 764	194	99	85
Pea						
beachpea, purple	*Lathyrus japonicus (maritimus)*	---	27	3	98	90
flat	*Lathyrus sylvestris*	---	33	4	98	93
Milkvetch						
cicer	*Astragalus cicer*	Cicer	320	36	95	75
Sainfoin	*Onobrychis viciaefolia*	Onar	40	4	90	75
Sweetclover	*Melilotus alba*	---	578	65	99	85
Trefoil						
big	*Lotus uliginosus*	Beaver	2 205	248	98	85
birdsfoot	*Lotus corniculatus*	Cascade	1 036	118	98	85
narrowleaf	*Lotus tenuis*	Los Banos	1 069	118	98	85
Vetch						
bramble	*Vicia tenufolia*	P-692	73	8	90	90
woollypod	*Vicia dasycarpa*	Lana	24	3	90	90

Source: Hafenrichter (1968:66-67).

☆ Culms, not seeds, are used. See text.

a Rate of seeding per ha varies widely in the area. Standard rates are available in technical guides in SCS offices and in other Federal and State agricultural offices.

b P-numbers are accession numbers assigned by SCS plant materials centers.

Note: NR = column headed Germination Percent was unreadable in copy available.

Table 26.10. Percent germination at constant temperatures in seeds of various species from King Christian Island and from near Inuvik, N.W.T.

Species	1°		5°		12°		20°	
	% Germination	Days[a]	% Germination	Days	% Germination	Days	% Germination	Days
Seeds from King Christian Island								
Phippsia algida	0	-[b]	16	32	40	5[c]	16	26
Oxyria digyna	8	21	4	10	25	25	30	14
Cerastium alpinum	0	-	0	-	36	25	36	30
Arenaria rubella	-	-	0	-	0	-	0	-
Ranunculus sabinei	0	-	0	-	100	19	68	32
Papaver radicatum	0	-	0	-	0	-	4	21
Cochlearia officinalis	-	-	0	-	0	-	0	-
Cardamine bellidifolia	-	-	0	-	-	-	-	-
Draba bellii	0	-	0	-	12	14	4	14
Saxifraga caespitosa	-	-	0	-	70	32	65	28
S. cernua (bulbils)	20	17	46	14	88	14	96	11
Potentilla hyparctica	0	-	0	-	20	14	0	-
Seeds from MacKenzie Delta								
Arctagrostis latifolia	0	-	-	-	-	-	96	6
Calamagrostis canadensis	0	-	-	-	-	-	90	8

Source: Bell (1975:67)

a Days indicates the number of days required for 90% of total germination. All tests used 25 seeds and were replicated twice.

b Dash indicates no data.

c After one month stratification at 2°.

Table 26.11. The effect of immersion in aerated and non-aerated water on seeds of several species from King Christian Island. Dash indicates no data.

Species and Treatment	1°		12°		20°	
	% Germination	Days	% Germination	Days	% Germination	Days
Phippsia algida						
on wet surface	0	-	12	32	16	26
immersed	0	-	16	25	12	21
immersed in aerated water	-	-	8	35	8	4
Ranunculus sabinei						
on wet surface	0	-	96	14	72	32
immersed	0	-	100	20	84	21
immersed in aerated water	-	-	100	14	84	21
Cerastium alpinum						
on wet surface	0	-	0	-	24	32
immersed	0	-	36	25	36	29
immersed in aerated water	-	-	4	22	60	28
Saxifraga caespitosa						
on wet surface	0	-	24	25	4	32
immersed	0	-	68	35	64	32
immersed in aerated water	-	-	-	-	-	-
S. cernua						
on wet surface	0	-	60	25	96	11
immersed	4	18	92	14	72	14
immersed in aerated water	-	-	26	5	92	5
Potentilla hyparctica						
on wet surface	0	-	0	-	-	-
immersed	0	-	20	14	-	-
immersed in aerated water	-	-	0	-	-	-

Source: Bell (1975:68)

Sourdough; Puccinellia sp. cv. Borealis; and Festuca rubra. The cultivar of Poa glauca is believed to be the first material of arctic origin to be released as a cultivar. Earlier papers by Mitchell and Mckendrick (1974) and Mitchell (1973b) also cited Festuca rubra and Deschampsia beringensis as favoured species, as well as Arctagrostis latifolia, Puccinellia borealis, and Calamagrostis canadensis.

Klebesadel (1973) presents the results of 20 years of observations on the performance of native Alaska grasses and legumes. Much of the information is applicable to revegetation. The paper also includes locally adopted varieties of introduced perennial grasses and legumes. No data are presented matching species or varieties to site conditions.

26.1 SUMMARY

Research on native grasses for mountain and foothills areas is relatively new, originating over the past ten to fifteen years. The majority of well-designed studies have originated in the past five to seven years. Most of this research has been done in Alberta and the western United States.

In Alberta, the Agropyron species have performed very well and are particularly suited to low elevation (subalpine) sites. Agropyron dasystachyum, A. subsecundum, and A. trachycaulum have been the best performers and selected lines of these species are currently being tested for licencing. Koeleria cristata has also shown promise as a lower elevation species. Deschampsia caespitosa and Poa alpina are two promising high elevation species.

Results for other species have not been as consistent or have yet to stand the test of time. Festuca saximontana, F. rubra, F. idahoensis, Stipa columbiana, Trisetum spicatum, Calamagrostis purpurescens, Poa interior, and Phleum alpinum are in early stages of research. Of these, Poa interior, F. saximontana, and T. spicatum are currently being intensively studied for high elevation reclamation.

Deschampsia caespitosa and P. alpina have been recognized as best adapted species for high elevation in the United States as well.

Agropyron trachycaulum, A. scribneri, and Phleum alpinum are also considered good species while Carex and Trisetum are considered to have potential but require further research.

Several alpine and subalpine forbs and legumes are considered useful for reclamation but to date research has been limited and quite superficial.

In arctic regions, research on native grasses and legumes is gaining momentum. Poa glauca cv. Tundra, Arctagrostis latifolia cv. Alyeska, Deschampsia beringensis, Calamogrostis canadensis cv. Sourdough, Pucinellia borealis, and Festuca rubra are all considered good candidate reclamation species. Only Festuca rubra has been used in both arctic and alpine regions.

In boreal and taiga areas, Alopecurus, Festuca, and Phleum performed well on wet, acid, peaty soils. Agropyron, Puccinellia, Elymus, and Bromus performed poorly on these sites but Bromus, Alopecurus, some Agropyron and one Elymus species were satisfactory for dry sites.

Grasses and Legumes for Soil Conservation in the Pacific Northwest and Great Basin States is a recommended handbook for reclamationists.

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27. USE OF NATIVE GRASSES AND FORBS IN REVEGETATION OF THE PLAINS REGION

DePuit and Coenenberg (1979b) tested seed mixes of improved native plant species (Table 27.1) at the Colstrip Mine in south-eastern Montana. Increasing the number of species in the seed mix increased the diversity without decreasing productivity (Table 27.2). Tests were carried out on a topsoiled (38 cm) reclaimed mine site with a semi-arid continental climate and 40.1 cm precipitation. Seed-beds were chisel plowed to 30 cm depth and fertilized with 16-20-0 at 39.6 kg N, and 16.3 kg P/ha.

Experimentation at Decker Mine, Montana has been somewhat fragmented over the years. A number of projects initiated in the early 1970s were not carried through to the late 1970s (Brown and Johnston 1975; Dollhopf and Majerus 1975). The authors point out that many native species components of relatively near climax plant communities are relatively poor pioneer species from standpoints of competitiveness and vigour.

Climate at the Decker Mine is similar to that described for Colstrip. Plots were topsoiled (15 cm settled to 10 cm) and disc plowed prior to seeding. Complete fertilizer was applied but rate and timing is not clear. Trials began in 1973; by 1975, Agropyron riparium, A. dasystachyum, Oryzopsis hymenoides and Puccinellia airoides were doing well.

Monoculture studies at Decker (DePuit, Coenenberg and Willmuth 1978) are shown in Table 27.3 (1974 after one year) and Table 27.4 (1977). Plots were established on well prepared sites (ripped, topsoiled, disc plowed, cultipacked, harrowed). Topsoil was sandy and natives that did well were adapted to sandy soil. Notable was the failure of Agropyron cristatum and Dactylis glomerata, usually good reclamation species in this area. A number of native species seed mixes were tested at Colstrip along with establishment methods. Only initiation of the project was described (DePuit, Coenenberg and Willmuth 1978).

Table 27.1. Seed mixes -- native species mixture establishment study Colstrip, Montana, 1977.

Plant Type[a]	Scientific Name	Common Name	Seed Source or Selection[b]
CSPG	Agropyron dasystachyum	Thickspike wheatgrass	Critana - abc
CSPG	Agropyron riparium	Streambank wheatgrass	Sodar - bc
CSPG	Agropyron smithii	Western wheatgrass	Rosanna - abc
WSPG	Bouteloua curtipendula	Sideoats grama	Pierre - bc
WSPG	Calamovilfa longifolia	Prairie sandreed	Goshen - abc
CSPG	Agropyron inerme	Beardless wheatgrass	Whitmar - c
CSPG	Agropyron trachycaulum	Slender wheatgrass	Alberta - c
CSPG	Oryzopsis hymenoides	Indian ricegrass	Paloma - abc
CSPG	Poa compressa	Canada bluegrass	Reubens - abc
WSPG	Andropogon hallii	Sand bluestem	N. Dakota - bc
WSPG	Schizachyrium scoparium	Little bluestem	Blaze - c
WSPG	Sporobolus cryptandrus	Sand dropseed	Colorado - c
CSPG	Stipa viridula	Green needlegrass	Lodorm - abc
S	Artemisia ludoviciana	Cudweed sagewort	S. Idaho - abc
S	Artemisia cana	Silver sagebrush	E. Montana - bc
S	Atriplex canescens	Fourwing saltbush	Wyoming - abc
S	Chrysothamnus nauseosus	Rubber rabbitbrush	E. Montana - c
S	Rosa woodsii	Woods rose	E. Montana - c
S	Amorpha canescens	Lead plant	Idaho - abc
F	Helianthus annuus	Annual sunflower	S. Idaho - abc
F	Balsamorrhiza sagittata	Arrowleaf balsamroot	S. Idaho - abc
F	Echinacea angustifolia	Black samson	E. Montana - abc
F	Helianthus rigidus	Stiff sunflower	E. Montana - abc
LF	Thermopsis montana	Montana thermopsis	Idaho - abc
F	Linum lewisii	Lewis flax	E. Montana - abc
LF	Petalostemum purpureum	Purple prairieclover	E. Montana - abc
F	Ratibida columnifera	Prairie coneflower	E. Montana - abc
F	Achillea millefolium	Western yarrow	S. Idaho - abc

Source: DePuit and Coenenberg (1979b).

[a] CSPG = Cool Season Perennial Grass; WSPG - Warm Season Perennial Grass; S = shrub or half-shrub; F = forb; LF = forb (legume);

[b] a = Seed Mix 1; b = Seed Mix 2; c = Seed Mix 3

Table 27.2. Effects of varied numbers of plant species in seeding mixture and seeding rate on stand aerial biomass, seeded species canopy cover, stand composition and diversity. Native species establishment study, Colstrip, Montana 1978 (second growing season).

	A. Mean of Seeding Mixtures:[c]			B. Mean of Seeding Rates:[e]		
	1	2	3	1	2	3
Aerial Biomass (kg/ha) for:						
Perennial grasses	1339.1	1398.2	1383.4	1144.0	1446.7	1530.2
Annual grasses	35.1	39.1	65.7	54.6	32.8	52.5
Legumes	400.3	329.8	669.2	536.1	359.6	504.1
Forbs[a]	43.0	43.3	51.5	49.4	51.2	37.2
Shrubs	418.8	251.3	383.2	447.6	258.7	346.8
Russian thistle	60.5	112.2	95.4	78.2	97.3	92.5
Total aerial biomass	2296.8	2173.9	2648.4	2309.0	2246.3	2563.3
Canopy Cover (%) for Seeded Species:						
Critana thickspike & Sodar Streambank Wheatgrass[b]	35.8	37.5	24.1	27.5	32.4	37.5
Whitmar Beardless Wheatgrass	-	-	0.9	0.4	0.3	0.2
Rosanna Western Wheatgrass	18.6	19.0	12.5	12.9	19.1	18.0
Slender Wheatgrass	-	-	27.1	8.4	10.9	10.5
Sand Bluestem	-	0.4	0.1	0.3	0.2	0.1
Pierre Sideoats Grama	-	0.8	0.6	0.3	0.5	0.7
Goshen Prairie Sandreed	0.8	0.8	0.1	1.3	0.3	0.2
Paloma Indian Ricegrass	7.5	4.4	2.5	6.2	3.7	4.5
Reubens Canada Bluegrass	0.4	0.5	0.1	0.5	0.3	0.2
Blaze Little Bluestem	-	-	-.1	T	-	T

continued.....

Table 27.2. Concluded.

	A. Means of Seeding Mixtures:[c]			B. Mean of Seeding Rates:[e]		
	1	2	3	1	2	3
Sand Dropseed	-	-	0.1	T	T	0.1
Lodorm Green Needlegrass	10.3	9.7	4.5	9.1	10.2	5.2
Purple Prairieclover	0.1	0.2	T[d]	0.1	0.2	T
Western Yarrow	-	0.2	-	0.2	-	T
Sunflower	0.1	0.2	0.3	0.3	0.1	0.1
Lewis Flax	0.7	0.7	0.9	0.5	0.5	1.3
Prairie Coneflower	0.2	-	T	-	0.2	T
Silver Sagebrush	-	T	T	T	-	T
Cudweed (Louisiana) Sagewort	-	-	T	T	-	-
Fourwing Saltbush	18.0	13.1	16.3	16.3	16.2	14.8
Rubber Rabbitbrush	-	-	0.1	T	-	T
Shannon-Weaver Function Diversity Index For Seeded Native Species	.68888	.69208	.75051	.81792	.76616	.74168
Shannon-Weaver Function Diversity Index for Entire Stand	.86123	.88520	.90673	.97100	.92204	.87433

Source: DePuit and Coenenberg (1979b:80).

a Excluding Russian thistle.

b Field differentiation of these two species impossible in 1978.

c Mixture 1 with 9, Mixture 2 with 13 and Mixture 3 with 19 seeded native perennial grass and shrub species; all three mixtures also contained a constant mix of 9 native forb species.

d T = trace (<0.1% cover)

e Data represent averages for drill and broadcast seeding method treatments. Drill rates 1, 2 and 3 were 28, 42 and 56 Kg P.L.S./ha respectively; Broadcase rates 1, 2 and 3 were 56, 84 and 112 Kg P.L.S./ha. Therefore, these data correspond to average seeding rates of 42, 56 and 84 Kg P.L.S./ha for Rates 1, 2 and 3, respectively.

Table 27.3. Mean seedling density, plant species evaluation, Colstrip, Montana, 08 May 1974 (all values in plants/m²).

Scientific Name	Common Name	Density
Elymus angustus	Altai wildrye	167
Agropyron elongatum	Tall wheatgrass	136
Agropyron riparium	Steambank wheatgrass[a]	113
Oryzopsis hymenoides	Indian ricegrass[a]	104
Agropyron trichophorum	Pubescent wheatgrass	77
Agropyron smithii	Western wheatgrass[a](Fall seeded)	71
Agropyron smithii	Western wheatgrass[a](Spring seeded)	69
Agropyron dasystachyum	Thickspike wheatgrass[a]	47
Andropogon hallii	Sand bluestem[a]	37
Buchloe dactyloides	Buffalograss[a]	34
Elymus triticoides	Beardless wildrye	33
Bromus inermis	Lincoln smoothbrome	28
Linum lewisii	Lewis flax[a]	25
Panicum virgatum	Switchgrass[a]	23
Calamovilfa longifolia	Prairie sandreed[a]	15
Bromus arvensis	Field brome	13
Dactylis glomerata	Orchardgrass	13
Elymus junceus	Russian wildrye	13
Schizachyrium scoparium	Little bluestem[a]	10
Elymus cinereus	Basin wildrye	9
Festuca elatior	Meadow fescue	8
Andropogon gerardii	Big bluestem[a]	7
Stipa viridula	Green needlegrass[a]	7
Bouteloua curtipendula	Sideoats grama[a]	5
Sitanion hystrix	Squirreltail[a]	5
Agropyron cristatum	Crested wheatgrass	5
Phleum pratense	Timothy	4
Agropyron trachycaulum	Slender wheatgrass[a]	4

continued ...

Table 27.3. Concluded.

Scientific Name	Common Name	Density
Festuca ovina var. duriuscula	Hard sheep fescue	3
Bromus brevis	Pampean brome	0
Bouteloua gracilis	Blue grama[a]	

Source: Adapted from DePuit, Coenenberg and Willmuth (1978).

[a] Native to Montana

Table 27.4. Mean rooted and canopy cover-derived frequency of 1973 plant species trials, Colstrip, Montana, 1977 (all values in %).

Species/Cultivar	Rooted Frequency	Cover Frequency
Agropyron cristatum	8[a]	12[a]
Agropyron dasystachyum[b]	68	74
Agropyron elongatum	83	83
Agropyron riparium[b]	48	48
Agropyron smithii[b]	84	85
Agropyron smithii[b] (Barton)	75	82
Agropyron trachycaulum[b]	16	16
Agropyron trichophorum	67	75
Andropogon hallii[b]	68	72
Andropogon gerardii[b] (Kaw)	34	40
Bouteloua curtipendula[b] (Butte)	67	76
Bouteloua curtipendula (Trailway)	60	68
Bouteloua gracilis[b]	3	3
Bromus arvensis	--	--
Bromus brevis	9	9
Bromus inermis	71	71
Buchloe dactyloides[b] (S.I.T.)	56	76
Buchloe dactyloides[b] (treated)	60	61
Calamovilfa longifolia[b]	43	60
Dactylis glomerata	--	--
Elymus angustus	69	79
Elymus cinereus	--	--
Elymus junceus	12[a]	12[a]
Elymus triticoides	--	--
Festuca elatior	--	--
Festuca ovina var. duriuscula	7	7
Linum Lewisii[b]	--[b]	1[a]

continued ...

Table 27.4. Concluded.

Species/Cultivar	Rooted Frequency	Cover Frequency
Oryzopsis hymenoides[b]	17	35
Oryzopsis hymenoides[b] (Oto)	10	12
Panicum virgatum[b]	41	53
Phleum pratense	24	26
Schizachyrium scoparium[b] (Blaze)	32	41
(Blaze)		
Schizachyrium scoparium[b] (local)	48	56
Sitanion hystrix[b]	--	--
Stipa viridula[b]	16	28

Source: Adapted from DePuit, Coenenberg and Willmuth (1978).

[a] Data considered invalid due to plot disturbance (initial wind erosion, seed blowout, thistle infestation, etc.)

[b] Native to Montana.

The Colstrip and Decker studies are reported in a number of progress reports. The material is quite complex in presentation. The reader is advised to review individual reports for details.

Sims and Redente (1974) tested a large number of native and introduced species in the Piceance Basin, Colorado. The region is semi-arid and subject to extreme temperature variation. Plants were tested in monoculture in four regions: (1) low-elevation pinyon/juniper Woodland; (2) mid-elevation sagebrush shrubland; (3) high-elevation pinyon/juniper woodland; and (4) mixed-mountain shrubland. "Favourable" and "harsh" sites were selected on the basis of slope, aspect, and existing vegetation. Three treatments were used: (1) control; (2) vegetation removed by scraping with minimal topsoil loss; and (3) vegetation removed by scraping and plowing to between 20 and 30 cm. Plants were fall seeded in 1972 and 1973, mainly to native SCS species, at high rates. One area was left for natural revegetation. Emergence and survival were examined for two years.

The results may be of dubious value to Alberta, mainly because of the semi-arid designation of the area, even though many species are native to Alberta. For that reason the summary is included here as presented by Sims and Redente (1974:106-107). The reader is advised to review the report for details:

"The grasses which showed the best adaptability at the big sagebrush location (1972 seeding) including various wheatgrasses such as Nordan crested, Critana thickspike, Jose tall, Amur and Oahe intermediate, Sodar streambank, Siberian, and Luna pubescent; along with mountain brome, Regar meadow brome and green needlegrass. The forbs and legumes which were most promising at this location included Madrid yellow sweetclover, bouncing-bet, Utah sweetvetch, Lewis flax, Rhizoma alfalfa, and Rocky Mountain penstemon. Along with the above grasses and forbs there were five browse species which also displayed superior emergence and survival: yellowbrush, Stansbury cliffrose, green ephedra, winterfat, and antelope bitter-brush.

"At the low elevation pinyon-juniper location...the list of grasses included the following species: Nordan crested wheatgrass,

Critana thickspike wheatgrass, Amur intermediate wheatgrass, Oahe intermediate wheatgrass, Sodar streambank wheatgrass, Rosana western wheatgrass, Luna pubescent wheatgrass, Regar meadow brome, and green needlegrass. Forbs and legumes which appeared to be promising during this study period were Penngift crownvetch, Utah sweetvetch, Lewis flax, Rhizoma alfalfa, Rambler alfalfa, Madrid yellow sweetclover, small burnet, and arrowleaf blasamroot. The number of browse species was more limited, with only yellowbrush, winterfar and green ephedra included in the list of recommended species.

"Species [found to be superior] at the high elevation pinyon-juniper location...included Nordan crested wheatgrass, Critana thickspike wheatgrass, Jose tall wheatgrass, Amur intermediate wheatgrass, Oahe intermediate wheatgrass, Siberian wheatgrass, Rosana western wheatgrass, Luna pubescent wheatgrass, mountain brome, Regar meadow brome, Manchar brome, and green needlegrass. Native and introduced forbs and legumes which displayed good adaptability...were Penngift crownvetch, Madrid yellow sweet clover, sweetanise, Utah sweetvetch, Rhizoma alfalfa, Palmer penstemon, Rocky Mountain penstemon, bouncing-bet, Gooseberry-leaf globemallow, verbena, and arrowleaf balsamroot. Finally, the browse species that were highly recommended at this location included common bladdersenna, green ephedra, desert bitterbrush, antelope bitterbrush, yellowbrush, Stansbury cliffrose, and black chokecherry.

"The grasses which displayed the best adaptability at the mountain browse location (1972 seeding) included various wheatgrasses such as: Nordan crested, Critana thickspike, Jose tall, Amur intermediate, Oahe intermediate, Sodar streambank, Siberian, Rosana western, Barton western, and Luna pubescent; along with mountain brome, Regar meadow brown, Manchar brome, C-43 basin wildrye, and green needlegrass. In addition to the grasses, the most promising forbs and legumes were Penngift crownvetch, Utah sweetvetch, Lewis flax, Rambler alfalfa, Rhizoma alfalfa, Madrid yellow sweetclover, sweetanise, Rocky Mountain penstemon, bouncing-bet and arrowleaf balsamroot.

"The group of browse plants that was recommended for this location consisted of all native species. This group was composed of the following species: common bladdersenna, desert bitterbrush, antelope bitterbrush, Stansbury cliffrose, green ephedra, and black chokecherry."

Monsen and Plummer (1978) provide an overview of problems encountered in arid areas (south-west U.S.) and plants suitable for reclamation of these areas. They suggest the use of nurse crops to prevent rapid invasion of weed species. The report deals with native and agronomic species with the approach being to use what is available and what "works". One species in widespread use is Achillea millefolium var. lanulosa. The species produces abundant seed and seedlings grow rapidly. The species is moderately palatable, adapted to a wide variety of sites, persists and increases under harsh conditions, has considerable longevity, and is not susceptible to insect attack. The reader is advised to refer to the article.

Thornburg and Fuchs (1978) have presented a paper on the general principles of plant species/varieties selection for sub-humid, semi-arid, and arid regions reclamation based upon experience of the USDA Soil Conservation Service. The paper lists some other literature of value in species selection (e.g., plant hardiness zone map, potential vegeation map). It also discusses the significance of the "ecotype" concept in selecting material for revegetation purposes. Experience suggests (Thornburg and Fuchs 1978:413) that "...an ecotype can be moved about 400 to 500 km north or 150-250 km south of the point of origin to areas of comparable soils and climate and give satisfactory performance. Movement east or west may be greater or less depending upon changes in elevation and precipitation." Thornburg and Fuchs also suggest that "... species selection should be based on the use planned and on the specific site conditions, not on whether a plant is introduced or native."

The paper divides the drier portions of the U.S. into nine plant growth regions and gives examples (not a complete list) of species that have exhibited satisfactory performance in each region.

The authors stated that in the northern Great Plains region the native Agropyron species are used extensively in mixtures (A. smithii, A. dasystachyum, A. spicatum, A. riparium, A. trachycaulum). Bouteloua gracilis also performs well but is generally not available. Stipa viridula is an important component of mixtures except in drier areas. Calamovilfa longifolia is adapted to sandy soils throughout the region. Alopecurus arundinaceus and Phalaris arundinacea are adapted to wet sites.

Packer and Aldon (1978) have summarized working methods in reclamation for the Northern Great Plains and south-western U.S. Included are species recommendations for Shortgrass Prairie Agropyron smithii, A. dasystachyum, Stipa viridula, Festuca ovina var. duriuscula, Bouteloua gracilis, B. curtipendula, and Andropogon gerardii.

Species suitable for other areas are mentioned (sand hills and forested areas of the south-west U.S., South Dakota, north-east Wyoming and south-east Montana). Plant species with tolerance to highly saline conditions are needed for revegetation purposes.

The Great Plains areas identified in and Packer and Aldon (1978) and Thornburg and Fuchs (1978) are roughly equivalent to Alberta's Brown Soil Zone.

27.1 SUMMARY

The wheatgrasses are the most successful and productive grasses that have been used in the Great Plains. Tests at the Colstrip and Decker mines and in the Piceance Basin have all been positive. Preferred species include Agropyron dasystachyum, A. riparium cv. Sodar, A. smithii cv. Rosanna, A. trachycaulum, and other varieties of A. dasystachyum and A. smithii. These species perform well in mixtures as well as individually.

Other species that have performed very well include Stipa viridula (except on dry areas), Andropogon hallii, A. gerardi, Bouteloua gracilis, B. curtipendula, and Bromus spp.

Species mentioned less frequently include Oryzopsis hymenoides, Pucinellia airoides, Buchloe dactyloides, Calamovilfa

longifolia, Panicum virgatum, Schizacnium scoparium, and Festuca ovina var. duriuscula.

Calamovilfa longifolia is recommended for sandy soils and Alopecurus arundinaceus and Phalaris arundinacea for wet sites.

Further research is required on tolerant species for saline soils.

Achillea millefolium is highly recommended in the literature as an exceilent forb for reclamation in plains regions. The species is a good seed producer, is fast growing, moderately palatable, adapted to many sites and harsh conditions, is insect resistant, and long lived.

Guidelines are given for movement of species. Ecotypes can be moved 400 to 500 km north or 150 to 250 km south of point of origin to areas of comparable soils and climate and will perform satisfactorily. Movement east or west may be greater or less depending upon elevation and precipitation.

The reader is advised to review the following references: DePuit and Coenenberg (1979a,b); DePuit and Dollhopf (1978); DePuit, Coenenberg and Willmuth (1978); Monsen and Plummer (1978); Packer and Aldon (1978); Thornburg and Fuchs (1978); DePuit, Willmuth and Coenenberg (1977), Dollhopf, Jensen and Hodder (1977); Meyn, Sundberg and Young (1976); Dollhopf and Majerus (1975); Sims and Redente (1974); Hodder et al. (1974); and Sindelar, Hodder and Majerus (1973).

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28. USE OF NATIVE GRASSES AND FORBS IN REVEGETATION OF OTHER GEOGRAPHIC REGIONS

A report edited by Bloch and Kilburn (1973) presents 12 papers dealing with revegetation of oil shales in the western United States. The shales have characteristics (high salt content, high pH, low N and P, and difficult wetting and water characteristics) peculiar to the resource and not particularly relevant to Alberta. However, readers may find some useful facts on mixing treatments, mulches, and methodologies to modify physical and chemical properties in order to grow native and exotic trees, shrubs and grasses, some of which could be used in Alberta. Because of the nature of the substrate (processed oil shale), however, no review will be presented here.

Aldon, Knipe and Garcia (1973) studied success of Agropyron smithii at two sites in New Mexico. Sites were at 2438 m elevation on materials derived from sandstone and 2256 m elevation on clay loam. Precipitation averaged 28 to 30.5 cm. Survival was 86% or better on the two sites after one year and 82% or better after two years. Regeneration from rhizomes was visible on 64% of the plants.

Chironis (1977) has published a guide of native and introduced species of grasses, forbs, shrubs, and trees for use on mine spoils in the eastern and western United States. The portion dealing with the eastern U.S. is irrelevant to Alberta as few, if any, of the species would be sufficiently cold-hardy to be used here. The reader should consult the text for western species.

Kuja and Hutchinson (1979) collected Arctagrostis latifolia, Hierochloe alpina, Carex bigelowii, and Artemisia tilesii from acid soil exposed to SO_2 near Cape Bathhurst in the Northwest Territories. They also collected Deschampsia caespitosa from tailings at Sudbury, Ontario, and Hordeum jubatum from roadsides in the Yukon. Species were tested on tailings from seven sites in the Yukon and Northwest Territories and one from Sudbury. Tailings had a wide range of pH and were extreme in concentration of one or more heavy metals. Artemisia grew on all tailings. Arctagrostis and Deschampsia did not grow on very acid (pH 3.0) tailings or tailings high in Pb, Zn, and Cd. Hordeum did not

grow at all on acid tailings. Hierochloe and Carex were not vigorous but showed acid and metal tolerance. The results should probably be viewed with some caution as a narrow provenance range of vegetation material was used considering the number of tailings sites.

Copper tailings in Utah have high salinity and severe N deficiency. Information indicates that native plants tested had no special adaptability to these conditions (Nielson and Peterson 1973).

Chosa and Shetron (1976) described methods of revegetating "slime" areas (very wet) of tailings ponds in the Midwest. Phalaris arundinacea planted in clumps survived 100% and worked well and Salix spp. was even better. Typha latifolia was seeded but did not succeed.

Down (1973) studied species and life forms on colliery tips of various ages in Great Britain (Table 28.1 and 28.2). Many of the species are native to Alberta. Down commented that artifical plantings of grasses and legumes on colliery wastes was contrary to natural revegetation. Artificial planting of hemicryptophytes was suggested. Hemicryptophytes comprised 68 to 79% of the number of species on each tip. Rosette hemicryptophytes declined from 32% on 12-year-old types to 12% on 98-year-old types. The rosette species were good pioneers because of their posession of tap root, and microclimate modification by basal leaves.

Table 28.1. Presence (X) or absence of certain species on coal tips in Great Britain.

Species	Soil Age (years)				
	12	15	21	55	98
Chamaenerion angustifolium	X	X			
Cirsium vulgare	X	X			
Leontodon taraxacoides	X	X	X	X	
Plantago major	X	X	X		
P. lanceolata			X	X	X
Holcus lanatus		X	X	X	X
Lotus corniculatus				X	X
Trifolium pratense				X	X
T. repens				X	X
Vicia sylvatica				X	X

Source: Down (1973).

Table 28.2. Life forms of species on coal tips in Great Britain.

Life Form	Soil age (years)				
	12	15	21	55	98
MM[a]	0[b]	7.1	0	7.9	0
M	4.5	0	7.1	10.5	2.9
Chh	4.5	7.1	3.6	5.3	5.9
H	9.1	7.1	2.6	2.6	5.9
Hp	4.5	10.7	3.6	21.1	32.4
Hs	22.7	32.1	35.7	21.1	29.4
Hr	31.8	25.0	32.1	23.7	11.8
TOTAL H	68.2	75.0	75.0	68.4	79.4
Gr	0	3.6	3.6	0	0
Grh	0	0	0	0	2.9
Th	22.7	7.1	10.7	7.9	8.8

Source: Down (1973).

[a] Key to Life Forms

MM -- Phanerophytes, woody plants with buds more than 25 cm above soil level, plants higher than 8 m.
M -- Phanerophytes, plants 2 to 8 m high.
Chh-- Herbaceous chamaephytes with buds above soil level but below 25 cm.
H -- Hemicryptophytes, herbs with buds at soil level.
H -- Undivided hemicryptophytes.
Hp-- Protohemicryptophytes with basal leaves smaller than stem leaves.
Hs-- Semi-rosette hemicryptophytes, basal leaves larger than stem leaves.
Hr-- Rosette hemicryptophytes, leafless flowering stems with basal leaf rosette.
Gr-- Geophytes with buds or roots.
Grh-- Geophytes with rhizomes.
Th-- Therophytes, passing the unfavourable season as seeds.

[b] Values are percentages of total numbers of species on each tip.

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29. USE OF NATIVE TREES AND SHRUBS IN REVEGETATION

29.1 NORTH-EASTERN (OIL SANDS) REGION

Vaartnou and Sons Enterprises Ltd. (1978), Selner and Thompson (1977), Vaartnou and Wheeler (1974), and Wheeler and Vaartnou (1974) carried out some of the earlier trials on tailings dikes and waste dumps in the Oil Sands area. Selner and Thompson planted over 31 000 native and introduced tree and shrub seedlings, primarily Salix fragilis var. basfordiana cv. Redher and Populus spp. (5158 and 8000 plants, respectively). The study considered planting method, planting time, and slope position. Site preparation consisted of two treatments: 10 cm of peat mixed into sand using a bulldozer, and 10 cm of peat on the surface with no mixing. Species were planted as bare-root, container, or cuttings (Populus balsamifera, local origin only). Several conifers (Picea mariana, Picea glauca, Pinus banksiana, P. contorta, P. albicaulis, Abies lasiocarpa, Larix laricina, and Pseudotsuga menziesii) were seeded as were several deciduous species (Betula papyrifera, Alnus crispa, A. tenuifolia, and Rosa woodsii).

Interpretation of these experiments was hampered by design parameters and the heavy mortality caused by rodent damage. The studies are being re-evaluated at this time in preparation for a final report.

Vaartnou's studies are probably the most intensive work on native shrubs in Alberta (Vaartnou and Sons Enterprises Ltd. 1978; Vaartnou and Wheeler 1974; Wheeler and Vaartnou 1974). These experiments, like those of Selner and Thompson (1977), contain voluminous data and were difficult to interpret.

Suncor (previously GCOS) planted 3100 trees and shrubs on their tailings dike in the spring of 1972. Seedlings were planted at 3 x 3 and 5 x 5 m spacing. Of the native species planted, Prunus pensylvanica, Populus spp., Betula spp., and Caragana had best survival. Elaeagnus commutata and Shepherdia spp. had very poor survival percentage. Salix and Populus were damaged by rodents, as was Caragana to a lesser degree (Berry and Klym 1974; Great Canadian Oil Sands Ltd. 1972).

Later plantings of several conifers on dikes and waste dumps (Pinus banksiana, P. contorta, P. banksiana x contorta, Picea glauca) were surviving reasonably well after one or two years. Survival for various years' plantings is given in Table 29.1 (Klym and Berry 1975).

In a study by Syncrude Canada Ltd., 1 m long Salix cuttings dipped in rooting hormone were planted 20 to 40 cm below ground on the Suncor dike. After 12 weeks, survival was approximately 15%. The site was low in organics and nutrients and most soil characteristics varied widely (Dai and Langevin 1978).

Lesko (1974a) hydroseeded several native shrubs in mixtures and with grasses and legumes on the Suncor dike. Picea engelmanni, P. glauca, Pinus contorta, Amelanchier alnifolia, Prunus virginiana, Cornus stolonifera, Elaeagnus commutata, and Rosa woodsii failed completely. Lesko advised against seeding trees and shrubs into well drained tailings sands with no peat and clay amendment and suggested that trees and shrubs be introduced into grass cover after the site has improved.

Lesko (1974b) also tested tree and shrub seedlings on sand dunes near Lesser Slave Lake. Plots were hydromulched with 225 kg/ha of fertilizer (10-30-10 and 40-0-0); 225 kg/ha Milorganite; 75 to 150 L Curasol AK; and 75 to 162 L Curasol AH plus 79 to 140 kg/ha of Tylose 666. All cuttings were coated with Curasol for moisture retention. Despite this preparation only Amelancher alnifolia (85%) and Artemesia candata (50%) plus Salix pole cuttings (60%, only five planted) were successful.

Populus balsamifera and Salix twig cuttings were 15% or less successful. The study recommended that trees be established two or three years after establishment of a protective grass cover and that areas should be planted (as cuttings or seedlings) rather than seeded.

Later trials by Fedkenheuer (1979a,b) tested the recommendations of Lesko (1974a). A test site was stripped to, and into, the C horizon and 1 m of tailings sand added. Plots were amended with two levels of clay, native sand, or lean tar sand. Peat was applied (15 cm), fertilizer added, and the site rotovated. A grass mix

Table 29.1. Survival of trees and shrubs planted in different years on tailings dikes and waste dump areas - Suncor Ltd., Fort McMurray, Alberta.

Common Name	Botanical Name	% Survival 1972	1973	1974	1975
TAR ISLAND TAILINGS DIKE TREE AND SHRUBS					
Planted in 1972					
	Caragana arborescens	56.6	45.0	45.0	45.0
Poplar	Populus griffithi	62.0	17.0	17.0	17.0
Aspen	Populus tremuloides	24.0	2.0	0.0	0.0
Birch	Betula papyrifera	52.0	16.0	15.0	15.0
Manchurian Elm	Ulmus pumila	99.0	80.0	79.0	60.0
Pincherry	Prunus pensylvanica	74.0	33.0	25.0	17.0
Choke cherry	Prunus virginiana	36.0	28.0	25.0	7.0
Buffaloberry	Shepherdia argentea	15.0	0	0	0
Wolf willow	Elaeagnus comutata	28.0	2.0	2.0	2.0
Willow	Salix spp.	28.0	28.0	25.0	7.0
Jack pine	Pinus banksiana	15.0	15.0	15.0	15.0
White spruce	Picea glauca	9.0	9.0	9.0	9.0
Planted in 1973					
Russian Poplar			36.0	13.0	8.0
Willow	Salix spp.		60.0	28.0	17.0
Planted in 1974					
Aspen	Populus tremuloides			50.0	32
Balsam-Poplar	Populus balsamifera			4.0	2
Birch	Betula papyrifera			24.0	19
Willow	Salix spp.			4.0	2
Spruce	Picea glauca			92.0	88
Jack pine	Pinus banksiana			72.0	66
Lodgepole pine	Pinus contorta			44.6	43
Pine-Hybrid				48.0	45
Balsam fir	Abies balsamea			30.0	4
Planted in 1975					
	Pinus banksiana-Bare Root				61
	Pinus banksiana-Containers				49
	Pinus contorta - Containers				51
	Picea glauca				51
	Picea mariana				36
Alder (Native)	Alnus sp.				24
Willow	Salix spp.				88
Maple	Acer negundo L.				77

continued ...

Table 29.1. Concluded.

Common Name	Botanical Name	% Survival			
		1972	1973	1974	1975
OVERBURDEN WASTE DUMP No. 7 SEEDLINGS					
Planted in 1974					
Spruce	Picea glauca			96	94
Jack pine	Pinus banksiana			72	55
Planted in 1975					
Lodgepole pine	Pinus contorta				2
Jack pine	Pinus banksiana				35
Spruce	Picea glauca				74
	Picea mariana				73

Source: Adapted from Klym and Berry 1975.

was drilled in. Trees and shrubs were planted spring and fall in 150 cc Spencer Lemaire plugs. Half the plots were fertilized annually; rodents were kept out. Survival is shown in Table 29.2.

A number of studies carried out in the eastern United States and in the Great Plains region of the United States and Canada have used species native to the oil sands (e.g., Pinus banksiana, Picea glauca, Populus spp., Salix spp., Amalanchier, Prunus, Shepherdia). While soils and climates were often different, the performance of these species may be of interest to those working with reclamation in the oil sands area. These studies are reported under Sections 29.3 and 29.4.

29.2 MOUNTAINS AND FOOTHILLS REGION

Unlike the situation with introduced species, considerable work has been done with native tree and shrub material in mountain and alpine areas.

In Alberta, Selner (1974, 1975) tested cuttings of Populus balsamifera from Lake Wabamun, Hinton, and Blairmore and Populus trichocarpa from Coal Creek on mine spoils in the east slopes. Populus spp. from southern regions were attacked by fungi and aphids in the greenhouse, while northern cuttings were more resistant. Trials were not successful in 1973. In 1974 a nurse crop was used to create more favourable microsites and trials were more successful. Conifers were tested as well. Pinus contorta var. latifolia (bare-root stock) and Picea glauca (both bare-root and container stock) averaged 83% survival at the Sterco, Loveth, and Coal Valley sites. In the Crowsnest area the same species averaged 75% at Tent Mountain and 52% at Grassy Mountain. Bare root Picea glauca performed best of the stock. No details of the experimental methods were provided.

At Luscar, Alberta, shrubs and trees were hydroseeded in mixes and with grasses and legumes (Lesko, Etter and Dillon 1975). Trials were carried out at two locations: (1) on weathered sandstone and shale spoil (undisturbed for 20 years) with 0 to 70% slopes of south-eastern to north-eastern exposure; and (2) on recent shale spoil of south-west exposure and 10 to 20% slopes. Tests considered slope gradients,

Table 29.2. Percent survival 1978 of native shrubs planted in 1977 on amended tailings sand at Fort McMurray, Alberta.

Species	Soil amendment																	
	Native sand				Lean tar sand				10 cm Mineral fines				20 cm Mineral fines				10 cm Mineral fines	
	Fert.[a]		Unfert.		Fert.		Unfert.		Fert.		Unfert.		Fert.		Unfert.		Fert.	
	S[b]	F	S	F	S	F	S	F	S	F	S	F	S	F	S	F	S	F
Alnus crispa	89	44	89	0	89	22	67	44	100	11	89	22	89	0	78	22	100	0
Amelanchier alnifolia	+[c]	78	+	89	+	89	+	100	+	100	+	100	+	100	+	89	-	-
Betula pumila var. *glandulifera*	+	56	+	78	+	67	+	0	+	56	+	33	+	0	+	33	-	-
Cornus stolonifera	78	89	100	11	67	44	100	67	89	22	89	44	89	44	78	56	-	-
Elaeagnus commutata	-[d]	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	67
Potentilla fruticosa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	100
Rosa acicularis	100	100	100	78	100	100	89	100	100	100	100	100	100	78	100	100	+	58
Salix spp	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	33
Shepherdia canadensis	+	89	+	42	+	100	+	100	+	78	+	89	+	89	+	100	-	-
Symphoricarpos albus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	100	75
Vaccinium vitis-idaea	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	63	25

Source: Fedkenheuer (1979b)

Note: Plants which died over winter (77/78) were replaced following spring assessment, so it is possible for fall survival to be higher than spring.

[a] Fert. = fertilized in 1978; unfert. = not fertilized in 1978.
[b] S = spring survival; F = fall survival.
[c] + = species planted in June, 1978.
[d] - = no species planted.

seeding time (fall and spring), slurry mix, and surface treatments (graded and buldozer packed). The shrub and tree seedings were complete failures and direct seeding of woody species was not recommended. Soil moisture, not soil surface temperatures, was considered most important in limiting germination and establishment. The relative effects on shrubs and trees versus herbaceous species were not clearly evaluated.

Vaartnou attempted revegetation with grass/legume/shrub mixes at Windy Point, an arid grassland site in Jasper National Park. Germination and establishment of Elaeagnus commutata, Rosa acicularis, and Juniperus horizontalis was unsuccessful (Harrison 1979, 1980).

A number of native shrubs were planted on steep road cuts (40 to 70%) in Washington (Tiedemann et al. 1976) on colluvium subsoil from granodiorite parent material and decomposed granodiorite, volcanic ash, pumice, and a mixture of these. Organic matter and nutrients were extremely low. After two years, survival and growth were evaluated (Tables 29.3 to 29.5). Survival of cuts was less than for fills, probably due to texture, depth, moisture holding capacity, and stability of soils. Small plants and lateral and slow growth contributed to poor survival. Seedling stems must be tall enough to survive inundation by loose material and root size must be small enough to provide easy planting with minimum disturbance.

Sambucus cerulea and Penstemon fruticosus seemed to be suited to a wide variety of sites. Rosa sp. and Amelanchier alnifolia were also good but vigour and growth was lower. Elevation did not appear to affect Rosa. The authors recommended that research be carried out on growth form, growth rate, physiological requirements and tolerance, the relation of plant requirements to disturbed soils and sites, and effects of fertilizers.

Howard, Rauzi and Schuman (1979) tested 85 species of woody plants (native and introduced) on six sites (five coal spoil; one uranium spoil) at elevations between 1372 and 2316 m in Wyoming and Colorado. Sites were graded and covered with 15 to 46 cm of topsoil. With the exception of one saline site, subsoil was not detrimental to plant growth. All species but one were propagated from cuttings and

Table 29.3. Percent survival two years after planting of bare-root shrubs on road cut and fill slopes, Entiat District of the Wenatchee National Forest, Washington.

Elevation (m)	Aspect	Type of Slope	Penstemmon fruticosa Bush penstemon[a]	Amelanchier alnifolia Service-berry	Sambucas coerulea Blue elder-berry[a,b]	Sympho-ricarpos Snow-berry
755	SE	Fill	45	--	62	--
792	SE	Cut	58	50	77	73
792	SE	Cut	47	58	87	--
914	SE	Cut	71	71	76	--
945	SE	Cut	20	60	67	--
1098	E	Cut	46	22	80	--
1098	E	Fill	86	86	78	--
1158	W	Cut	49	80	77	--
1216	SE	Cut	40	69	70	--
1251	SE	Cut	53	40	--	--
1463	W	Cut	37	77	--	--
1478	S	Fill	80	88	--	--

Source: Adapted from Tiedemann et al. (1976).

[a] Vigour good

[b] Vigour and growth rate decline above 1200 m.

Table 29.4. Percent survival of bareroot shrubs planted on road cut slopes of the Colville National Forest, Washington.

Elevation (m)	Aspect	Amelanchier alnifolia Serviceberry[a]	Rosa Wild rose	Symphoricarpos Snowberry
853	N	--	22	80
853	SE	--	80	--
884	SW	--	50	22
914	S	--	--	--
914	S	--	10	0
914	SE	--	--	--
945	SE	--	90	--
975	E	85	--	--
1005	SE	85	85	--

Source: Adapted from Tiedemann et al. (1976).
[a] Growth poor - vigour fair

Table 29.5. Percent survival of bare-root shrubs planted on road cut slopes of the Okanogan National Forest, Washington.

Elevation (m)	Aspect	Penstemmon fruiticosa Bush penstemon[a]	Rosa Wild rose	Prunus virginiana Chokecherry[b]	Arctostophylos uva-ursi Kinnikinnick
853	S	62	54	42	--
975	NW	--	71	--	--
1036	SE	--	70	--	--
1127	SE	--	30	--	--
1158	SE	50	50	--	0
1310	S	0	--	--	--
1341	W	--	70	--	--
1371	S	40	80	35	--
1463	S	--	85	--	--

Source: Adapted from Tiedemann et al. (1976).
[a] Vigour fair to good
[b] Vigour poor

transplanted to containers. Shrubs and trees that are relevant to Alberta and performed well are shown in Table 29.6.

Pinus ponderosa has been used (Megahan 1974) for erosion control purposes at 1433 m ASL on steep (70 to 75%) slopes. Pine was planted and seeded with erosion net and straw mulch, with and without fertilizer. Planting was at 0.5 and 0.8 m spacing. Compared to grass seeded with erosion net, straw mulch and fertilizer, planted trees reduced annual average erosion rates by 48, 32 and 51% in each of three years. Recommended spacing was 0.9 or 1.2 m (although this was apparently not tested for erosion control) and Pinus contorta was recommended for alpine areas.

Scotter (1976) and Campbell and Scotter (1975) found Luetkea pectinata to be a possibility for planting on high elevation disturbed areas. However, results were very preliminary. Moisture was most critical.

29.3 PLAINS REGION

The emphasis of reclamation in plains regions has been on cereal and forage crops. In the Canadian prairies at least, woody species have received very little attention. There are a number of uses for shrubs and trees on the plains, including wildlife habitat, shelter belts, and aesthetics.

Flavelle (1974) presented a descriptive evaluation of trees and shrubs planted since 1943 on spoil banks near Estevan. The spoil was saline, with a pH of 8.0 to 8.5. The area was quite ecologically uniform before mining (microclimate and pedology); however, the spoil banks were quite variable (frost pockets, moisture, and salinity) and had lost considerable organic matter. The Saskatchewan Department of Tourism and Renewable Resources, Forestry Branch (1973) noted that the early plantings of trees and shrubs (1949, 1957) had met with complete failure. Soil moisture and salinity had the most effect on survival in early and more recent trials. While soil at the edge of small lakes and ponds was quite saline, there were areas further from the edge where moisture was adequate and salt was not a major problem.

Table 29.6. Woody plant species, planting locations and growth and survival data taken at the end of the 1977 growing season. Plantings on topsoil and on overburden at Oak Creek, Colorado, are listed separately.

Year set	Botanical name	Common name	Gillette			Glenrock			Shirley Basin			Hanna			Kremmerer			Oak Creek			Oak Creek		
			Ht.[a] cm	Spr. cm	Surv. %	Ht. cm	Spr. cm	Surv. %	Ht. cm	Spr. cm	Surv. %	Ht. cm	Spr. cm	Surv. %	Ht. cm	Spr. cm	Surv. %	Ht. cm	Spr. cm	Surv. %	Ht. cm	Spr. cm	Surv. %
1976	*Artemisia abeinthium*	Common wormwood				37	44	100	12	16	100							32	24	50	47	55	100
1976	*A. cana*	Silver sagebrush	26	27	100	22	32	100	8	10	100	-	-	0	4	9	20	21	21	75	23	29	50
1975	*A. tridentata*	Basin big sagebrush				-	-	0	12	19	33												
1975[b]	*A. vulgaris*	Mugwort wormwood	56	39	100	26	33	92	32	31	100	7	7	70	5	10	45	5	13	75	14	24	100
1975[c]	*Caragana arborescens*	Siberian peashrub[c]	72	35	93	48	28	92	34	16	100				2	4	78	17	14	100	33	13	100
1975	*Chrysothamnus nauseosus*	Rubber rabbitbrush	39	35	100	30	33	67	5	8	100	12	13	42	4	7	57	36	38	75	29	33	50
1975[d]	*Elaeagnus angustifolia*	Russian olive[c]	29	18	90	55	78	83	13	14	100	13	8	40	-	-	0	27	22	100	37	41	100
1976	*E. commutata*	Silverberry	11	11	33	8	8	100	14	7	100	-	-	0	-	-	0	-	-	0	13	11	25
1975	*Juniperus scopulorum*	Rocky Mountain juniper	32	27	100	22	17	50	11	12	70							49	29	75			
1976	*Lonicera tatarica*	Tatarian honeysuckle[c]	30	32	100	36	28	100	9	11	100												
1975	*L. tatarica* cv. *rosea*[e]	Rose tatarian honeysuckle	23	21	33	51	19	100	10	8	100				-	-	0	20	25	100	31	34	100
1976	*L. halimifolium*	Matrimonyvine	47	62	100	58	48	100	26	35	100	18	16	100	4	8	33	43	33	100	40	58	100
1975	*Pinus ponderosa*	Ponderosa pine	15	10	100	16	10	67	12	4	90							12	7	100	11	9	100
1975	*Populus angustifolia*	Narrowleaf cottonwood[c]	102	97	37	33	44	75	2	2	11							22	19	75	26	40	100
1976	*Potentilla fruticosa*	Bush cinquefoil	-	-	0	12	12	33	5	6	33				-	-	0	-	-	0	15	11	25
1975	*Rhus trilobata*	Skunkbush sumac[c]	18	16	73	14	14	100							-	-	0	14	15	100	21	24	100
1976	*Rosa arkansana*	Arkansas rose[c]	10	19	100	7	19	100	5	8	100				4	5	25	10	18	50	9	22	100
1975	*Shepherdia argentea*	Buffaloberry	34	19	86	29	34	100	7	12	83							22	12	50	15	15	75
1976	*Symphoricarpos albus*	Common snowberry	18	17	100	20	17	60	4	7	100	9	10	33	-	-	0	21	21	100	19	17	100
1976	*S. vaccinioides*	Whortleaf snowberry										8	7	100									
1977	*Tanacetum vulgare*	Common tansy[c]													6	7	50						
1976	*Viburnum opulus*	Highbush cranberry	17	10	100	-	-	0	-	-	0							-	-	0	-	-	0

Source: Adapted from original table in Howard, Rauzi and Schuman (1979)

[a] Ht., Spr., and Surv. are height, spread and survival, respectively.
[b] Dashes indicate plant did not grow; blank spaces indicate species was not planted.
[c] Generally, 8 to 12 plants of each species set in each location in 1975.
[d] Planted as bareroot stock.
[e] Generally, 3 to 5 plants of each species set in eash location in 1976 and 1977.
Species native to Alberta but not sub-species or variety.

Elaeagnus angustifolia, Salix spp., Prunus virginiana, and Shepherdia canadensis were used with good success. Several native trees (Populus deltoides, Crataegus rivularis, Salix spp., Elaeagnus, and Fraxinus pennsylvanica) had very good survival after one year. It was recommended that trees be established on north and east facing slopes. Elaeagnus was recommended as an excellent species for lower slopes.

Organic matter had an apparent influence on the growth of Fraxinus pennsylvanica. Rooted stock of Populus and Salix did better than cuttings. Salix (nigra, damascus, alba var. vitteliina, purpurea) and Fraxinus pennsylvanica did well on levelled spoil piles. Howe (1979) rated Shepherdia and Prunus virginiana highly as shelter belt species.

After three years of study, recommendations were made to modify topography by widening and lowering ridges and filling valleys; topsoil was also recommended.

Generally, the information presented in the early progress reports is very descriptive and difficult to interpret (Saskatchewan Department of Tourism and Renewable Resources, Forestry Branch 1973).

Hodder et al. (1974) seeded 16 shrub species in mixture with grasses at Colstrip, Montana in 1972. The site was prepared by ripping and chiselling. Shrubs were seeded separately and overseeded with 3.4 kg/ha each of Bromus inermis and Agropyron elongatum, and 2.2 kg/ha of Onobrychis sp. After one year, only four species (two native to Alberta), had produced dense stands. Others were reproducing, but at low density (Table 29.7).

Pinus ponderosa (2-0 bare-root stock) was planted at Colstrip on bare spoil, spoil covered with scoria, and spoil with straw mulch. After three years, mortality was virtually 100% and was attributed to poor planting technique and competition from Salsola kali, although straw mulch decreased mortality in the first and second years.

Studies at Decker (Dollhopf and Majerus 1975) attempted various shrub trials. However, interpretation of results was difficult.

Shrubs were seeded directly into 10 to 15 cm of poor quality topsoil, disced prior to seeding, and fertilized with 56-112-168 kg/ha

Table 29.7. Species seeded in shrub seeding study at Rosebud Mine, Montana, 1972.

Scientific Name	Common Name	1973 August 09 Density (m^2)
Artemisia cana[a]	Silver sagebrush	0
Artemisia nova	Black sagebrush	0
Artemisia tridentata[a]	Big sagebrush	0
Atriplex canescens	Fourwing saltbush	57.6
Atriplex confertifolia	Shadscale	1.1
Atriplex gardneri	Gardner saltbush	37.3
Atriplex nuttallii[a]	Nuttall saltbush	40.5
Chrysothamnus nauseosus	Rubber rabbitbrush	ND
Chrysothamnus viscidiflorus	Green rabbitbrush	5.3
Chrysothamnus viscidiflorus var. stenophyllus	Little rabbitbrush	1.6
Elaeagnus angustifolia	Russian olive	1.1
Purshia tridentata	Antelope bitterbrush	1.1
Rhus trilobata[a]	Skunkbush sumac	1.6
Rosa spp.[a]	Wild rose	1.1
Sarcobatus vermiculatus[a]	Greasewood	10.7
Symphoricarpos albus[a]	Snowberry	0

Source: Hodder et al. (1974).

[a] Native to Alberta

of N-P-K, respectively. Fall seeded plots were refertilized in spring with 90 kg N and 112 kg P/ha. Of 18 shrubs seeded only Atriplex nuttallii and Sarcobatus vermiculatus produced seedlings (12.4 and 42.7/m^2, respectively) and only from fall seeding. In a second study shrubs were individually broadcast seeded (1000 seeds/m^2) in fall on an east-facing slope. The site was chiselled, harrowed, covered with 15 cm of topsoil, cultipacked following seeding, and fertilized with 45 to 56 kg/ha of N-P respectively. Once again only Atriplex nuttallii and Sarcobatus vermiculatus produced good stands.

In another study shrubs were fall sown and planted on a site that had various depths of buffer material over saline spoil covered by 15 cm of topsoil. The site was fertilized with 56 to 67 kg/ha of N-P the following spring and 45 to 56 kg/ha of N-P one year later. Buffer depth had no effect on seeded shrubs (as might be expected, Table 29.8; success of planted material varied with buffer depth and results were relatively poor, Table 29.9). Later analyses showed the buffer material to be worse than the spoil and this study was subsequently abandoned.

Tubeling seedlings planted at the Decker Mine (Caragana arborescens, Symphoricarpos spp., Artemisia frigida, Prunus virginiana, and Rhus aromatica var. trilobata) had survival percentages of 33 to 83% after one year but very few plants were in good condition. Dollhopf and Majerus suggested that this was a good technique for vegetation establishment under harsh conditions. However, these were large diameter paper tublings planted in 20 cm holes on topsoiled spoil. The article did not indicate that the researchers had a great deal of experience with container stock and results are quite preliminary. The potential of the technique may be overemphasized.

Also at Decker (Dollhopf and Majerus 1975) shrub mixtures were seeded directly onto "scoria", a reddish baked clay of low moisture holding capacity. Plots were broadcast seeded and fertilized (84, 56, 28 kg/ha of N-P-K, respectively) in spring. Atriplex canescens and Sarcobatus vermiculatus were superior to other species (Table 29.10).

Orr (1977) carried out some very good studies on shrub planting in a semi-arid (30.5 to 40.6 cm) region of the Great Plains.

Table 29.8. Density (plants/m^2) of shrub species seeded on the buffer study at the Decker Mine, Montana.

Scientific Name	Buffer Depth (cm) 0	25	50	75
Artemisia tridentata	0.89	0	0	0
Artemisia cana	0.44	0	0	0
Artemisia nova	0	0	0	0
Atriplex canescens	9.78	4.72	3.54	4.13
Atriplex confertifolia	6.22	0.59	6.49	4.72
Atriplex nuttallii	54.52	30.09	34.81	51.92
Atriplex gardneri	11.11	5.90	14.16	19.47
Chrysothamnus nauseosus	15.56	24.26	9.44	23.60
Chrysothamnus viscidiflorus	6.22	4.13	3.54	3.54
Chrysothamnus viscidiflorus var. stenophyllus	16.30	7.67	5.31	1.18
Sarcobatus vermiculatus	22.22	17.19	20.65	11.21
Rosa woodsii	0	0	0	0
Iva axillaris	0	1.18	0	0
Yucca glauca	0	0	0	0
Eleagnus angustifolia	0	0	0	0
Prushia tridentata	1.44	0	0	0

Source: Dollhopf and Majerus (1975).

Table 29.9. Percent survival of shrubs planted on the buffer study at the Decker Mine, Montana.

Species	Buffer Depth (cm)			
	0	25	50	75
Caragana	44	76	84	12
3-Leaf Sumac	20	20	20	12
Siberian Salt-tree	0	0	0	0
Russian Olive	0	4	4	0

Source: Dollhopf and Majerus (1975).

Table 29.10. Seedling establishment on a scoria fill, Decker Coal Mine, Montana.

Species	Density (plants/m^2)			
	1972 July 12	1973 July 11	1974 July 16	Mean
Mixture 1				
Skunkbrush sumac	4.9	1.3	2.0	2.7
Rubber rabbit brush	2.2	1.3	1.0	1.5
Four-wing saltbush	7.8	6.0	6.0	6.6
				10.8
Mixture 2				
Greasewood	12.2	7.1	10.0	9.8
Broom snakeweed	1.8	2.2	2.0	2.0
Green ash	0.0	0.0	0.0	0.0
				11.8
Mixture 3				
Ponderosa pine	0.7	0.4	0.0	0.4
Creeping nightshade	4.2	1.6	1.0	2.3
Common honeysuckle	0.9	0.0	T	0.3
				3.0
Mixture 4				
Shadscale	0.7	0.7	0.0	0.5
Common bladdersenna	3.1	1.8	1.0	2.0
Antelope bitterbrush	2.9	0.4	2.0	1.8
				4.3
Mixture 5				
Black sagebrush	6.0	3.8	2.0	3.9
Yucca	0.6	0.4	T	0.3
Four-wing saltbush	4.2	4.7	6.0	5.0
				9.2

Source: Dollhopf and Majerus (1975).

In one study bare-root stock was planted in good-quality spoil previously drilled to Agropyron-Stipa-Atriplex; rows were clean cultivated to eliminate competition. Half the plants were irrigated. In a modified study half the stock was container stock. Results are shown in Table 24.1. There were significant differences between species of bareroot stock; Fraxinus pennsylvanica outperformed other species. Weather varied considerably from year to year and obviously year of planting was important. Irrigation and container planting also had effects (see Chapters 39 and 41). Overwintering loss was apparently very important.

Nord (1977) discussed suitable low-flammability, durable, and low-growing shrubs for roadside planting, recreation sites, and mine spoils in semi-arid and arid regions. Only Atriplex was of much concern to Alberta (one species A. nuttalii grows in Alberta). Some Atriplex species contain mycorrhizae following growth on soils of low fertility. Practically all species have high mineral content in the foliage and thus have a high osmotic potential and morphological characteristics which allow them to absorb moisture effectively from ground or atmosphere. Several are good browse species for game birds and game mammals. The species are easy to establish from seed or as potted seedlings (some vegetatively). Young plants are susceptible to damage and destruction by small animals.

McArthur, Giunta and Plummer (1974) stressed the general importance of shrubs for big-game animal and livestock support and as cover and stabilizers for disturbed areas. The report rated a number of species highly for soil stabilization (Table 29.11). In a separate report Plummer (1977) has rated more than 40 shrub species according to general usefulness in reclamation (Table 29.12). Both tables have been edited to include only species native to Alberta.

Thornburg and Fuchs (1978) have identified good species and planting requirements for shrubs in dry regions. Use of woody species was limited to favourable moisture conditions. Elaeagnus angustifolia, Fraxinus pennsylvanica, Rhus aromatica var. trilobata, Shepherdia

Table 29.11. Species values for rangeland restoration and soil stabilization in the northwestern United States.

Species	Value for		Adaptation to vegetal types[a]
	Range Restoration	Soil Stabilization	
Black chokecherry (*Prunus virginiana*)	Medium	High	MB, JP, A, BS, SA
Golden current (*Ribes aureum*)	Medium	High	MB, JP, BS, WM
Blueberry elder (*Sambucus cerulea*)	High	High	MB, JP, A, BS
Tatarian honeysuckle (*Lonicera tatarica*)	Medium	High	MB, JP, BS
Rubber rabbitbrush (*Chrysothamnus nauseosus*)	Medium	High	BS, JP, MB, A, BG
Woods rose (*Rosa woodsii ultramontana*)	Medium	High	MB, JP, A, BS
Big sagebrush (*Artemisia tridentata*)	High	High	BS, JP, MB, A, SA
Fringed sagebrush (*Artemisia frigida*)	Medium	High	BS, JP, BG, SS, A
Serviceberry saskatoon (*Amelanchier alnifolia*)	Medium	Medium	MB, JP, BS
Skunkbush sumac (*Rhus trilabata*)	Low	High	JP, MB, BS, SD
Winterfat (*Eurotia lanata*)	High	High	JP, SS, BS, BG, MB

Source: Adapted from McArthur, Giunta and Plummer (1974).

[a] A = Aspen; BB = Blackbrush; BS = Big sagebrush; MB = Mountain brush; JP = Juniper-pinyon; SA = Subalpine; M = Meadow; SS = Shadscale-saltbush; IS = Inland saltgrass; BG = Black greasewood; AA = Arctic alpine; SD = Sand dune

Table 29.12. Shrubs and trees species adaptation attributes and adaptation to disturbance areas in the northwestern United States.

Common and scientific name	Established by seed	Established by transplants	Seed production and handling	Natural spread (seed)	Natural spread (vegetative)	Growth	Soil stability	Adaption to disturbance	Soil preference Acid (AC) Alkaline (AL)	Type or community to which species is adapted[a]
Alder, thinleaf *Alnus tenuifolia*	3[b]	4	3	4	4	4	4	2	AC/AL	BS, JP, MB, A
Aspen, quaking *Populus tremuloides*	0	4	2	0	4	4	5	4	AL/AC	A
Birch, water *Betula occidentalis*	2	3	4	3	2	3	4	3	AC/AL	MB, JP, A, BS
Boxelder[c] *Acer negundo negundo*	4	5	5	4	2	4	4	3	AL/AC	MB, A, JP
Buffaloberry, silver *S. argentea*	2	3	3	3	3	3	4	3	AL	JP, MD, IS, WH
Ceanothus, snowbrush *C. velutinus*	2	4	2	3	4	4	5	4	AC/AL	MB, A
Chokecherry, black[c] *P. virginiana melanocarpa*	3	4	4	3	5	4	5	5	AC/AL	MB, A, JP
Cinquefoil, bush *Potentilla fruticosa*	2	5	3	3	3	3	3	3	AC/AL	WH, A, SA, MB
Cottonwood, black *Populus thrichocarpa*	2	4	2	3	3	4	4	4	AL/AC	MB, A, BS
Cottonwood, narrowleaf *P. angustifolia*	1	4	2	3	4	4	4	2	AL/AC	MB, A, BS
Currant, golden *Ribes aureum*	4	5	4	5	5	4	4	4	AL/AC	MB, JP, WH
Currant, sticky *R. viscosissimum*	2	3	2	3	3	2	4	3	AC/AL	SA, A, MB
Douglas-fir[c] *Pseudotsuga menziesii menziesii*	1	3	4	1	0	3	3	3	AC/AL	SA, MB
Elder, blueberry *Sambucus cerulea*	3	5	5	3	5	5	4	4	AC/AL	MB, MD, A
Elder, redberry *S. racemosa pubens microbotrys*	3	3	5	2	5	5	5	3	AC/AL	SA, A, MB
Fir, subalpine *Abies lasiocarpa*	1	3	4	3	0	2	4	3	AC/AL	SA, A
Greasewood, black *Sarcobatus vermiculatus*	3	3	3	3	2	4	3	3	AL	SS, MD, SD, IS
Honeysuckle, bearberry *Lonicera involucrata*	1	4	2	2	3	3	3	2	AC/AL	A, SA, MB
Honeysuckle, tatarian *L. tatarica*	3	5	4	3	3	4	3	3	AL/AC	MB, JP, MD
Juniper, common *Juniperus communis*	2	3	2	2	3	2	4	4	AC/AL	MB, A, SA
Juniper, Rocky Mt. *J. scopulorum*	2	3	4	3	3	4	3	4	AC/AL	MB, A, JP, MD
Maple, mountain *Acer, glabrum*	4	4	4	3	4	3	3	4	AC/AL	MB, A, JP
Matchbrush (or broom-snakeweed) *Gutierrezia sarothrae*	3	5	3	5	0	5	3	5	AL	JP, BS, MD, SD
Matrimonyvine *Lycium halmifolium*	1	5	1	0	5	4	5	4	AL/AC	JP, MB, BS
Nightshade, bittersweet *Slanum dulcamara*	3	4	3	4	4	4	3	4	AL/AC	MB
Peashrub, Siberian *Caragana arborescens*	3	5	4	3	3	4	3	4	AL/AC	MB, JP, MD
Penstemon, bush *Penstemon fruticosus*	3	4	4	4	4	4	4	5	AC	MB, A
Pine, limber *Pinus flexilis*	1	3	4	3	0	3	4	4	AL/AC	MB, A, SD
Pine, ponderosa *P. ponderosa*	3	4	4	4	0	4	5	4	AC/AL	MB, A
Rabbitbrush, alkali rubber[c] *Chrysothamnus nauseosus appressilis*	4	4	3	4	5	5	5	5	AL	IS, MB, SS, BS
Rabbitbrush, mountain rubber[c] *C. nauseosus salicifolius*	4	4	4	4	3	5	5	5	AL/AC	MB, JP, A, SA, BS
Rabbitbrush, green rubber[c] *C. nauseosus graveolens*	4	4	4	5	3	5	5	4	AL	BS, JP, MD
Rabbitbrush, white rubber[c] *C. nauseosus albicaulis*	5	4	4	4	3	5	5	4	AL/AC	BS, JP, MB, MD
Rose, woods *Rosa woodsii ultramontana*	4	4	4	3	5	3	4	5	AL/AC	MB, JP, A, SA

continued...

Table 29.12. Concluded.

Common and scientific name	Established by seed	Established by transplants	Seed production and handling	Natural spread (seed)	Natural spread (vegetative)	Growth	Soil stability	Adaption to disturbance	Soil preference Acid (AC) Alkaline (AL)	Type or community to which species is adapted [a]
Russian-olive *Elaeagnus angustifolia*	3	4	5	4	3	4	4	4	AL/AC	MB, JP, IS, SD
Sagebrush, big [c] *Artemisia tridentata tridentata*	4	5	4	5	3	5	4	5	AL	MD, JP, MB, SD
Sagebrush, fringe *A. frigida*	3	5	3	4	3	5	4	3	AL/AC	MD, SD, JP, SA
Sagebrush, mountain [c] *A. tridentata vaseyana*	4	5	3	5	1	5	5	5	AC/AL	A, MB, BS, SA
Sagebrush, silver [c] *A. cana cana*	3	5	4	4	4	5	5	5	AC/AL	MB, A, SA, JP
Serviceberry, Saskatoon *Amelanchier alnifolia*	3	3	3	3	3	3	4	4	AL/AC	MB, JP, A
Snowberry, common *Symphoricarpus albus*	3	5	3	5	5	5	5	5	AC/AL	MB, A
Snowberry, western *S. occidentalis*	3	5	3	4	5	5	5	4	AC/AL	MB, A
Spruce, Engelmann *Picea engelmanni*	2	3	4	2	0	3	4	3	AC/AL	SA, A
Sumac, skunk bush *Rhus trilobata*	3	5	4	3	3	3	4	4	AC/AL	MB, JP, MD, SD, C
Virginsbower, western *Clematis ligusticifolia*	2	4	4	3	4	4	4	4	AL/AC	MB, JP, BS
Willow, Scouler *Salix scouleriana*	-	4	-	-	3	3	4	4	AC/AL	MB, A, SA

Source: Adapted from original table in Plummer (1977)

[a] JP - Juniper-pinyon; MB - Mountain brush; BS - Big sagebrush; MD - Northern desert shrubland; SD - Southern desert shrubland; SS - Salt shrubland; IS - Inland saltgrass; A - Aspen; SA - Subalpine; AL - Alpine; WM - Wet meadows; C - Chaparral

[b] 1 Very poor; 2 Poor; 3 Medium; 4 Good; 5 Very good.

[c] Species native to Alberta but not necessarily subspecies or variety.

argentea, Prunus virginiana, Lonicera tatarica, and Salix were recommended.

29.4 OTHER GEOGRAPHIC REGIONS

Very few shrubs native to the eastern United States and Canada are suitable for reclamation in Alberta, and in fact none were encountered in the reclamation literature reviewed. A few tree species are potentially useful for Alberta.

Bourdo and Willis (1975) reported on Pinus banksiana and Picea glauca as species tested on gravel pits. Picea glauca had 87% survival after 15 years and Pinus banksiana 78%. Picea glauca was more slow growing, initially, than Pinus banksiana. (However, this is a natural characteristics of the species.)

In Appalachia and the Midwest, P. banksiana has performed quite well on mine spoil of a variety of conditions. Picea glauca performance has not been as consistent (Davis 1973; Geyer 1972; Czapowskyj 1970; Sopper 1970; Czapowskyj and McQuilkin 1966). In most cases information provided was inadequate for detailed evaluation.

Pinus banksiana success has been good on very acid spoil (pH 3.5). However, a drastic growth reduction was noted at 15 years. No explanation was given (Wheeler 1965).

Limstrom (1960) reported survival and height of three tree species on strip mined soils after two years:

	Sand	Stony loam	Stony clay
Pinus banksiana	59(0.21)	84(0.24)	94(0.27)
Fraxinus pennsylvanica	91(0.30)	94(0.27)	97(0.46)
Populus deltoides	71(0.91)	64(0.67)	70(0.79)

It is not known if trees were seeded or planted. Heights (m) are given in brackets.

29.5 SUMMARY

Several species (*Prunus pennsylvanica*, *Populus* spp., *Betula papyrifera*, and *Caragana*) have shown some positive results after four years on dike slopes in the North-east Oil Sands region. *Pinus* and *Picea* have shown good survival after one or two years on dike slopes and waste dumps.

Eleagnus commutata and *Shepherdia canadensis* have shown poor survival. *Salix*, *Populus*, and *Caragana* have shown to be very susceptible to rodent damage.

Seeding of most native shrubs and trees into grass swards or on bare sites, even with very elaborate site preparation and amendment, has been unsuccessful. Only *Amelanchier alnifolia* and *Artemesia candata* showed any success. Planting after grass is established is recommended.

Planting of shrubs into grass swards is being studied. Early (two-year) results were good for *Amelanchier alnifolia*, *Rosa acicularis*, and *Shepherdia canadensis*. Data are inconclusive for *Symphoricarpos albus*, *Potentilla fruticosa*, *Elaeagnus commutata*, *Cornus stolonifera*, *Betula pumila*, and *Alnus crispa*.

Well-designed studies of trees and shrubs for reclamation have been lacking until very recently but are now being initiated. Data from large projects initiated by Selner and Vaartnou should be condensed to obtain useful information in handbook form.

Several conifers (*Pinus contorta* var. *latifolia*, *Picea glauca*, *Pinus ponderosa*) have been successful in montane to alpine sites.

Sambucus cerulea and *Penstemon fruticosus* seem suited to a wide variety of sites and elevations. *Rosa* and *Amelanchier alnifolia* are also good species but vigour and growth were lower. Elevation did not seem to affect *Rosa* spp.

Small plants with lateral or slow growth are not successful on slopes.

Northern clones of *Populus* appeared to be more disease- and insect-resistant than southern clones.

Seeding of shrubs and trees is not recommended.

Research is recommended on growth form, growth rate, physiological requirements and tolerance, plant/site relationships, and fertilizers.

In the Plains region of Canada, only limited research has been carried out on older mine spoils in Saskatchewan. Elaeagnus, Salix, Prunus virginiana, Shepherdia canadensis, Populus deltoides, Crataegus rivularis, and Fraxinus pennsylvanica all did well. Trees were recommended on east slopes. Elaeagnus was excellent on lower slopes and Fraxinus pennsylvanica and Salix on levelled spoil.

Results are generally skimpy in the Plains region. Seeding of shrubs has not been successful, particularly into grass mixtures. On a variety of sites (poor and good spoil; topsoil) and under a variety of site preparations, Atriplex nutallii and Sarcobatus vermiculatus (seeded and planted) were the only two species to do well out of 16 tested. Atriplex is a good species as a wildland browse source. It is mycorrhizal and has high osmotic potential and thus has good moisture characteristics. The species is very easy to establish.

Fraxinus pennsylvanica and E. angustifolia have been the best species on semi-arid areas.

Plummer (1977) has recommended species for soil stabilization and general reclamation. Thornburg and Fuchs (1978) recommended several species for dry regions, the best being E. angustifolia, F. pennsylvanica, Rhus aromatica var. trilobata, Shepherdia argentea, Prunus virginiana, Lonicera tatarica, and Salix spp. However, these species were limited to sites with favourable moisture.

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SECTION IX

A COMPARISON OF NATIVE AND NON-NATIVE SPECIES FOR RECLAMATION

30. A COMPARISON OF NATIVE AND NON-NATIVE SPECIES FOR RECLAMATION

30.1 GRASSES AND LEGUMES

Native and agronomic species have been used in mixes and in studies and test plots of individual species. A few studies have attempted to compare native to agronomic species subjectively, however statistically tested quantitative evaluations are virtually non-existent.

Researchers for the most part have a tendency towards one type of material or the other. In Alberta, for instance, Vaartnou (Chapters 25 and 29) worked almost exclusively with native species while Selner's work (Chapters 21 and 24) was weighted heavily to the use of agronomic or introduced material. This type of "bias" is evident in most other regions of the United States and Canada.

Perhaps the advice of Moore, Ellis and Duba (1977:279) should be given more careful consideration in revegetation schemes. They stated: "...revegetation efforts should concern themselves with the successional status of a species, rather than whether the species is introduced or native. Competitive weeds may be expected on nearly all reclamation sites and it may be more useful to plant introduced perennial grass species which establish easily and show some competitive parity with alien weeds rather than attempting to replant higher seral stage native species. Conversion programs may then be applied at a later date to encourage the establishment of native species when the sere has advanced to a point which favours their success."

30.1.1 North-east (Oil Sands) Region

No studies have been carried out in the Oil Sands region that have been designed to actually compare native and introduced species, nor were there studies from other areas that were relevant to that region.

30.1.2 Mountains and Foothills Region

Both Macyk and Steward (1977) and Lesko, Etter and Dillon (1975) have carried out tests using native and agronomic grasses in

mountainous regions. In neither case were studies designed to compare natives to agronomics. However, Lesko concluded that native species did not appear to have an advantage over introduced species in the first two growing seasons after seeding at Luscar. Macyk also had limited success with native species compared to agronomics at Grand Cache. In both cases plots were fertilizer; more heavily in the Macyk study which also included amendments with other materials.

The Alberta Forest Service is comparing native and agronomic species (individually and as mixes) at Cadomin, Alberta, in the Eastern Slopes (Takyi and Russell 1980; Russell and Takyi 1979). The plants are tested on raw spoil and on mineral subsoil and plots were fertilized. After one growing season all species germinated well but agronomics had better plant cover than the natives (which was less than 10%). Results are very preliminary and work is continuing.

Brown has initiated some of the best designed studies of native versus agronomic grasses and legumes at high elevation. Preliminary work (Brown et al. 1976) indicated that mixtures of native species were more successful than mixtures of introduced species. While the latter may do better in the first and second seasons, natives catch up in the third season and go on to outperform the introduced species in vigour, cover, production, etc. Species were not grown in competition (i.e., native and introduced mixed); however, the authors suggest that a mixture will give best results. Klock, Tiedemann and Lopushinsky (1975), on the other hand, found that mixing species was a disadvantage because it affected yield of individual species.

Brown and Johnston (1976) tested native versus introduced mixes (Table 30.1) at high elevation (2950 m) on the Beartooth Plateau in Montana. The site was very acid; precipitation is 114 to 152 cm per year. Seeding rate was 56 kg/ha and fertilizer (16-16-16) was applied at 111 kg N/ha. Topsoiling versus no topsoiling was also tested. In the first year of the study precipitation was much below normal, which may be the reason that introduced species did not respond to fertilizer. After one year, native plant density was much higher than introduced on topsoiled plots and on fertilized spoil (Table 30.2).

Table 30.1. Native and introduced species seeded at the McLaren Mine, Montana, and the seeding rates used.

Species	Seeding rate (kg/ha)
NATIVE	
Tufted hairgrass (*Deschampsia caespitosa*)	17.0
Alpine bluebrass (*Poa alpina*)	14.2
Alpine timothy (*Phleum alpinum*)	14.2
Spike trisetum (*Trisetum spicatum*)	0.6
Slender wheatgrass (*Agropyron trachycaulum*[a])	5.8
Spreading wheatgrass (*Agropyron scribneri*)	0.6
Woolly pussytoes (*Antennaria lanata*)	0.6
Mountain dryad (*Dryas octopetala*)	0.6
Sedge (*Carex paysonis*)	2.4
	56.0
INTRODUCED	
Meadow foxtail (*Alopecurus pratensis*)	17.0
Timothy (*Phleum pratense*)	8.5
Smooth brome (*Bromus inermis*)	11.3
Intermediate wheatgrass (*Agropyron intermedium*)	5.6
Slender wheatgrass (*Agropyron trachycaulum*[a])	5.6
Alta fescue (*Festuca arundinacea*)	5.6
Orchardgrass (*Dactylis glomerata*)	2.4
	56.0

Source: Brown and Johnston (1976).

[a] Two strains of this species were used: a native strain growing near the site, and a commercially available strain.

Table 30.2. First-year results of plant density on revegetation plots at the McLaren Mine, Montana, (average number of plants per m^2).

	Topsoil		Spoil	
	Fertilizer	No Fertilizer	Fertilizer	No Fertilizer
Introduced	360	401	84	26
Native	1306	1044	895	96

Source: Brown and Johnston (1976).

At the same site, Brown and Johnston (1978) compared native and agronomic grass species transplanted as plugs with or without a straw/asphalt mulch. The native plants had greater survival (75%) than the introduced species (39%) after one year.

Comparison of native and agronomic species under different treatments was carried out in Idaho on acid mine spoils at 2500 m elevation. Various fertilizer, liming, irrigation, and mulch treatments were used (Farmer, Richardson and Brown 1976). Figure 30.1 indicates the response of native, non-native, and mixed vegetation on overburden, topsoiled, and irrigated plots. None of the mixes did well on overburden (control plots) regardless of treatment. On topsoiled and irrigated plots the introduced and introduced-native mixes outperformed the native mix. Fertilizer produced the greatest response on the introduced and introduced native mixes as well.

Brown (1973) measured transpiration rates for two introduced species (Bromus inermis and Agropyron intermedium) and one native species (Hesperochloa kingii) at high elevation in Utah (2900 m). The transpiration rates were greatest for the introduced species, suggesting that these species would suffer more severely under drought conditions.

University of Alaska studies (Mitchell 1973) have not found native species to be the panacea they are sometimes claimed to be. They often require strict matching to site, are commonly poor producers of viable seed, and seed may be difficult to clean and handle. Commercial varieties adapted to the north are more vigourous in their seeding year than native plants. Many native plants appear to sacrifice seed production for vegetative growth and propogation, which sometimes may be a detriment. However, once established, native species, in contrast to cultivars, are well adapted to site and climate and need virtually no management to persist and grow. In an overview paper on native and introduced species for Alaska, Mitchell noted that established stands of introduced species did not appear to present a permanent barrier to natural invasion of native species.

In contrast, Van Cleve (1977) noted that in Alaska (more southerly Boreal sites) introduced species performed poorly without

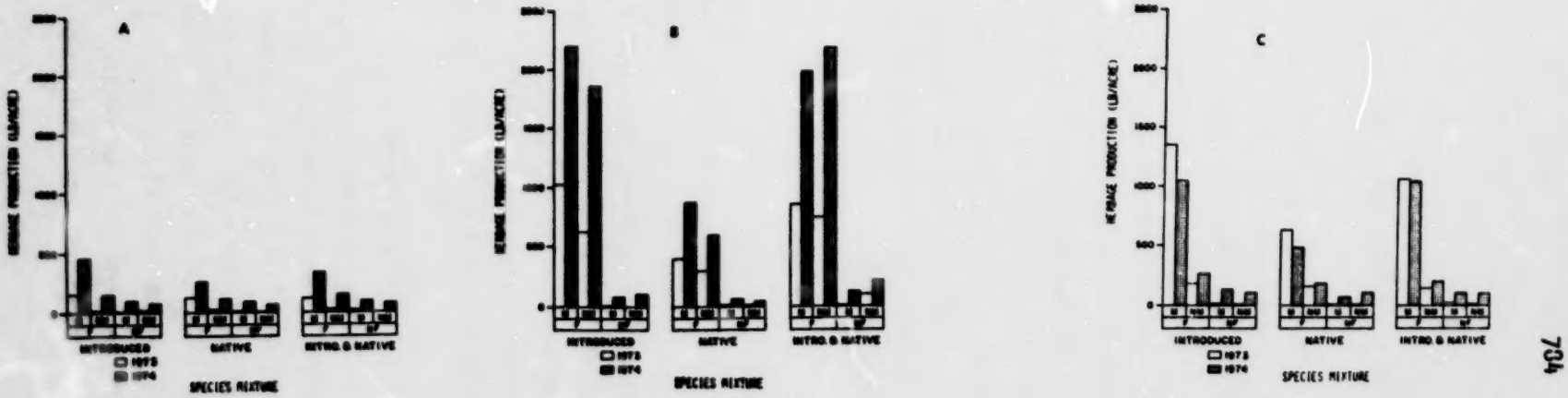

Figure 30.1. Average dry-weight vegetative producton, Blackbird Mine, Idaho, compared for 1973 and 1974: A, control main plot, B, topsoil main plot, C, irrigated main plot.

Source: Farmer, Richardson and Brown (1976)

fertilizer treatment. After five years even the best introduced species showed a marked decline.

Mitchell's (1976) work in the high Arctic indicated that seed production from native stands was insufficient for a revegetation project. Ecotypic differences were critical "in this region of marginal growing conditions." Different varieties of the same species and members of closely related species demonstrated distinct differences in adaptability. Other studies in tundra areas (Hernandez 1973a,b; Dabbs 1974) have indicated that Calamagrostis canadensis and Arctagrostis latifolia are the best performing natives, although they establish more slowly. Hernandez recommended Calamagrostis for boreal sites and Arctagrostis for those in the Arctic. Poa pratensis and Festuca rubra cv. Arctared are the most successful agronomics. Festuca rubra cv. Boreal also rates quite highly (Hernandez 1973a,b).

30.1.3 Plains Region

Vaartnou carried out a number of experiments with native species for roadside reclamation in Alberta in 1974 and 1976. Wheeler and Yarish reported on these in 1978 (Wheeler and Yarish 1978:14): "...with few exceptions the majority of the species that could be evaluated were licensed varieties of cultivated grasses and legumes planted as a cover crop or as a companion species alongside the native species." Only Festuca ovina persisted on all plots in the mixed prairie zone and is suggested as a good species for roadside reclamation where tall growth is undesirable.

The work of Richardson et al. (1975) and Farmer et al. (1974) at the Decker Mine in Montana is an interesting comparision to their similar work at high elevation in Idaho (Farmer, Richardson and Brown 1976). All-native, all-introduced, and combined mixes were tested with fertilizer, mulch, topsoil, and irrigation treatments. Native seed was local; seeding rate for all mixes was 28.6 kg/ha (viable). Seed-beds were ripped to 25 cm depth, tilled with a harrow cultivator to 15 cm, and then packed with a cultipacker and harrowed to 5 cm depth. Seed mixes are shown in Table 30.3. Native grasses performed quite well and

Table 30.3. Seed mixtures used in native versus agronomic species trials, Decker Mine, Montana.

Species	Grams per subplot	kg/ha
NATIVE SEED MIXTURE		
Green needlegrass	3	5.0
Western wheatgrass	4	6.7
Blue grama	2	3.4
Little bluestem	1	1.7
Sideoats grama	2	3.4
Indian ricegrass	1	1.7
Slender wheatgrass	3	5.0
Big bluestem	1	1.7
Total	17	28.6
INTRODUCED SEED MIXTURE		
Fairway crested wheatgrass	2	3.4
Nordan crested wheatgrass	2	3.4
Russian wildrye	3	5.0
Pubescent wheatgrass	2	3.4
Intermediate wheatgrass	2	3.4
Smooth brome (Manchar)	2	3.4
Winter rye	2	3.4
Tall wheatgrass	2	3.4
Total	17	28.6
NATIVE + INTRODUCED SEED MIXTURE		
Fairway + Nordan crested wheatgrass	3	5.0
Green needlegrass	2	3.4
Smooth brome	2	3.4
Western wheatgrass	3	5.0
Russian wildrye	2	3.4
Blue grama	1	1.7
Intermediate wheatgrass	2	3.4
Slender wheatgrass	2	3.4
Total	17	28.6

Source: Adapted from Richardson et al. (1975).

better than expected in the first year. Several of the more favourable treatments yielded native grass stands that would provide good erosion protection to the soil. In the first year the introduced mixture performed best, averaging 885 kg/ha and the natives poorest (705 kg/ha). Yields greatly improved in the second year and the smallest average yield (1956 kg/ha) came from introduced species (Figure 30.2). There did not appear to be any interaction of species and treatments.

At Colstrip (DePuit, Coenenberg and Willmuth 1978) studies of seed mixes began in 1974. All seeding was done in spring as was fertilization (four rates). Mixtures were: all native; 2/3 N / 1/3 I; 1/2 N / 1/2 I; and all introduced. The area was prepared by ripping at 2.4 m intervals, chiselling, cultipacking followed by seeding, and re-cultipacking. Mixtures contained shrubs and legumes as well as grasses.

First year emergence and density was highest for mixes containing introduced species, the all-introduced being highest. After four years the 1/2/1/2 mixture produced the highest perennial grass development; the pure native mixture produced the lowest mean cover (although perennial grass cover was equal to other mixes, Table 30.4). Fertilizer (above a minimal rate: 36-45-12 kg/ha of N, P_2O_5, K_2O) did not increase yield of natives significantly, but did increase that of mixes containing agronomics (Table 30.5). Patterns confirmed inhibition of native species sown in mixtures containing even a low proportion of naturalized introduced species and greater efficiency of fertilizer use by naturalized introduced species. They also suggested that adequate and diverse native species establishment may be enhanced if certain naturalized introduced species (such as crested and tall wheatgrass) are eliminated from seeding mixtures. Newly developed strains of native species may enhance performance of native mixtures. Stand diversity also was highest when vigorous naturalized introduced species were omitted or seeded in low amounts.

In a study started in 1972, DePuit, Coenenberg and Willmuth (1978) tested the relative performance of native (18% by weight) and agronomic species, sown in mixture along with a nurse crop of Triticum

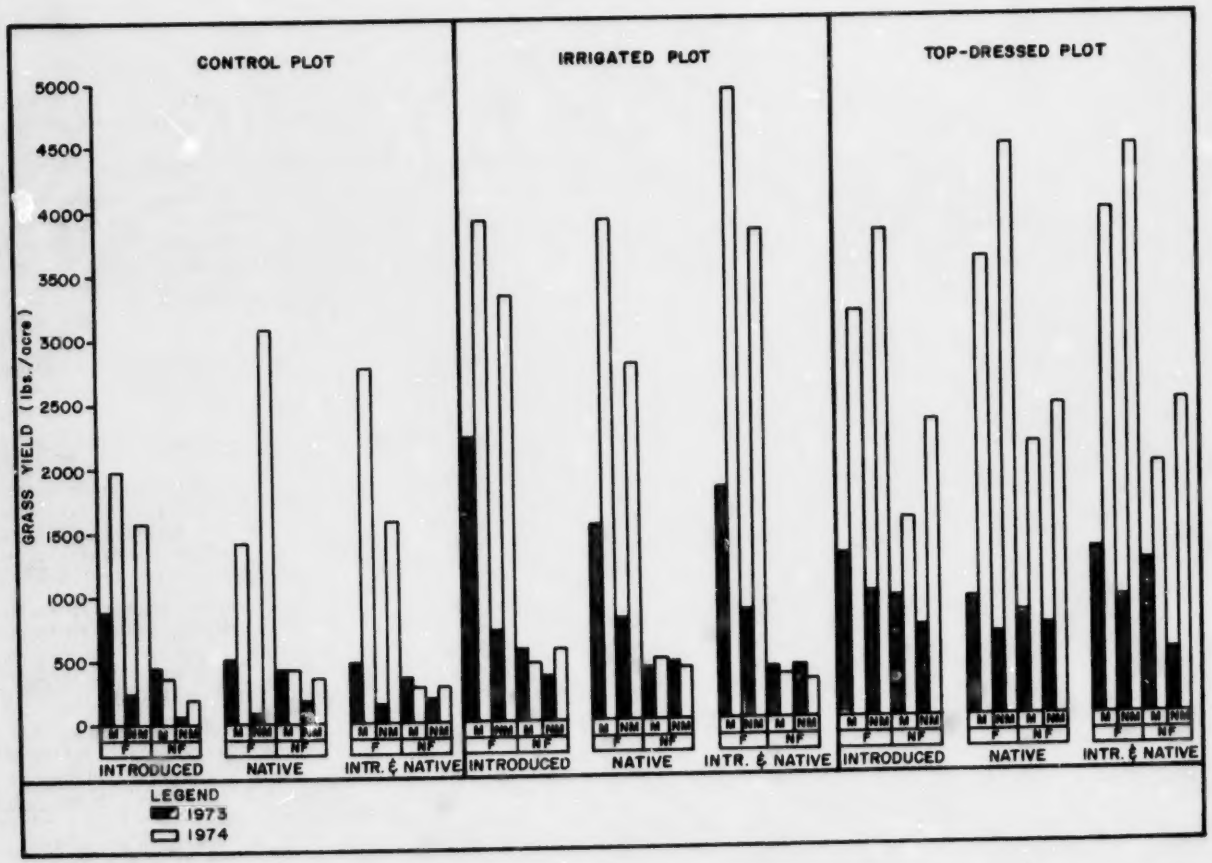

Figure 30.2. Comparison between mean dry-weight grass production for each plot by subplot treatments for years 1973 and 1974.

Source: Richardson, J.A., (1975)

Table 30.4. Mean vegetation canopy cover by vegetation class, native versus introduced species study, Colstrip, Montana, 1977 (all values in percent)[a].

Treatment	Total perennial grasses 1977	Total legumes[b] 1977	Total shrubs 1977	Litter 1977	Bare ground 1977
1. Mixture A (all native)					
No fertilization	1.6a	ND	ND	1.0	95.0
Low fertilization	11.5b	ND	1.3	3.0	92.0
Moderate fertilization	25.0c	ND	ND	15.3	79.7
Heavy fertilization	10.8b	ND	2.2	6.0	89.0
2. Mixture B (2/3 native + 1/3 introduced)					
No fertilization	8.2a	5.3	0.1	2.0	93.0
Low fertilization	23.2b	19.7	ND	7.7	87.3
Moderate fertilization	25.7b	8.0	1.7	42.3	52.7
Heavy fertilization	17.3b	ND	ND	12.0	83.0
3. Mixture C (1/2 native + 1/2 introduced)					
No fertilization	16.6a	44.4	ND	27.0	68.0
Low fertilization	25.4b	30.0	ND	18.0	77.0
Moderate fertilization	49.0c	10.3	ND	21.7	73.3
Heavy fertilization	64.4c	1.3	ND	44.0	51.0
4. Mixture D (all introduced)					
No fertilization	2.0a	14.4	ND	16.7	78.3
Low fertilization	27.3b	15.3	ND	25.3	69.7
Moderate fertilization	37.9c	ND	ND	28.0	67.0
Heavy fertilization	28.0bc	3.0	ND	9.3	85.7
5. Mean of all mixtures under:					
No fertilization	7.1a	16.0	Ta	11.7	83.3
Low fertilization	21.9b	16.3	0.3b	13.5	81.5
Moderate fertilization	34.4b	4.6	0.4b	26.8	68.2
Heavy fertilization	30.1b	1.1	0.6b	17.8	77.2
6. Mean of all fertilization levels for:					
Mixture A (all native)	12.2a	ND	0.9	6.3	88.7
Mixture B (2/3 native + 1/3 intr.)	18.6ab	8.3	0.5	16.0	79.0
Mixture C (1/2 native + 1/2 intr.)	38.9c	21.5	ND	27.7	67.3
Mixture D (all introduced)	23.8b	8.2	ND	19.8	75.2

Source: Adapted from DePuit, Coenenberg and Willmuth (1978)

[a] Fertilizer rate values within specific year-mixture-class data sets followed by different letters significantly different at the 5% level.

[b] Legume data in 1977 questionably low due to excessive grasshopper defoliation.

Table 30.5. Mean aerial biomass data for seeded species, native versus introduced species study, Colstrip, Montana, 1977 (all values in kg/ha, dry weight basis).

Treatment	Perennial grasses [a]	Legumes [b]	Shrubs	Total Seeded species Biomass [c]	Litter
1. Mixture A (all native)					
No fertilization	21.1a	3.6	3.6	28.3	25.0
Low fertilization	298.6b	44.7	118.4	461.7	719.6
Moderate fertilization	274.7b	7.7	14.0	296.4	532.1
Heavy fertilization	273.6b	ND	ND	273.6	2249.9
2. Mixture B (2/3 native + 1/3 introduced)					
No fertilization	75.0a	164.5	ND	239.5	78.6
Low fertilization	205.6b	40.2	1.2	247.0	652.3
Moderate fertilization	256.2b	16.0	250.9	523.1	472.7
Heavy fertilization	1041.1c	T	212.4	1226.5	2083.4
3. Mixture C (1/2 native + 1/2 introduced)					
No fertilization	170.4a	381.4	ND	551.8	418.2
Low fertilization	229.9ab	74.9	ND	304.8	460.4
Moderate fertilization	640.4c	102.9	ND	743.3	908.1
Heavy fertilization	283.2b	3.1	ND	286.3	537.6
4. Mixture D (all introduced)					
No fertilization	45.8a	108.2	ND	154.0	205.9
Low fertilization	250.9b	138.2	ND	389.1	965.4
Moderate fertilization	475.2c	45.2	ND	520.4	775.2
Heavy fertilization	677.3d	3.0	ND	680.3	2149.9
5. Mean of all mixtures under:					
No fertilization	78.1a	164.4	0.9a	243.4	181.9
Low fertilization	246.3b	74.5	29.9b	350.7	699.4
Moderate fertilization	411.6bc	43.0	66.2c	520.8	672.0
Heavy fertilization	562.1c	1.5	53.1c	616.7	1755.2
6. Mean to all fertilization levels for:					
Mixture A (all native)	217.0a	14.0	34.0	265.0	881.7
Mixture B (2/3 native + 1/3 introduced)	387.7b	55.2	116.1	559.0	821.8
Mixture C (1/2 native + 1/2 introduced)	330.9b	140.6b	ND	471.5	581.1
Mixture D (all introduced)	362.3b	73.7	ND	436.0	1024.1

Source: DePuit, Coenenberg and Willmuth (1978:96)

a Values followed by different letters significantly different at the 5% level.

b Legume and total biomass data questionable due to excessive grasshopper defoliation of legumes.

aestivum and Sorghum sudanense at Colstrip. Plots were heavily fertilized in 1972, 1973, 1974, with 84, 90, 90 kg/ha N, respectively, plus 56, 121, and 121 kg/ha P_2O_5, respectively. In 1974, 22 kg/ha K_2O was also applied.

The use of a nurse crop appeared to reduce invasion of weed species. Legumes made up a large part of the biomass in the second growing season but declined sharply as perennial-grass biomass increased greatly in response to fertilization. This was followed by physical and biological effects of a large litter build up. This decline of legumes in response to litter build up also occurred in other studies at Colstrip even when fertilizer was still being applied. The total crop was dominated from the beginning by agronomic species (mainly Agropyron cristatum, Bromus inermis, and Medicago sativa).

In another similar study, the same grass species dominated but Agropyron elongatum and Dactylis glomerata were also prevalent. Medicago and Astragalus cicer seemed to hold their own during nitrogen depression periods while Onobrychis, not an efficient nitrogen fixer, declined markedly.

Ries, Sandoval and Power (1978) compared the effect of topsoiling and fertilizing on the establishment and productivity of crested wheatgrass as compared to a mix of native grasses (Stipa viridula, 20%; Agropyron smithii, 35%; A. trachycaulum, 15%; Andropogon scoparius, 10%; Bouteloua curtipendula, 20%). Both were drill seeded at 16.8 kg/ha. After three years only Agropyron smithii and Stipa viridula were successfully established. However, this study was not a direct comparison of natives versus agronomics.

In Colorado (Cuany 1974) there has been little success in using native legumes for forage crops because of difficulties in collecting sufficient quantities of seed and poor seedling vigour. The emphasis has been placed on adapted varieties of introduced species. Of these, Trifolium pratense, T. hybridium and Medicago sativa have done well, with Medicago the best performer.

30.2 TREES AND SHRUBS

Studies that quantitatively or qualitatively compare native and introduced trees and shrubs are virtually non-existent in the literature. Therefore this section will not be subdivided by regions.

Trials in Pennsylvania (Shuffstall and Medve 1979) indicated that native trees outperformed exotics on mine spoils. However, these researchers admitted exotics have a role to play. Klym and Berry (1975) also reported that native (volunteer) Populus and Betula have greater survival and growth than imported stock on tailing dikes in the Oil Sands region of Alberta.

Monsen and Plummer (1978) rated various introduced and native shrubs for dryland revegetation (Table 30.6; edited for relevancy to Alberta). The rating considered establishment by seed, seedling growth rate, competitive ability, and seedling drought tolerance.

Van Epps and McKell (1978:352) advised very strongly that "plant materials destined for use in harsh environments should be collected by those who are intimately aware of the conditions where the plants would be expected to survive....In general, commerical seeds are not as suitable as those collected directly from specific harsh sites unless the source is known and has similar site conditions. Many shrub seedlings fail their rehabilitation assignment because they grew from non-adapted seed that originated on a dissimilar or unknown site."

30.3 SUMMARY

Fertilizer treatments and species mixtures (native and introduced) greatly affect performance and have not been well researched. Of importance is the particular species used; some are too dominant to be used in mixtures, particularly some agronomic species.

There have been no studies relevant to the North-east region of Alberta specifically comparing native to introduced (agronomic) species.

Information from the Rocky Mountains and foothills indicates that natives have no advantage over introduced species. Those studies showed introduced species to be at least as good or better under heavy

Table 30.6. Attributes of some woody plants for arid land plantings.

Common Name & Scienfific Name	Establish-ment by Seed	Seedling Growth Rate	Compet-itive Ability	Seedling Drought Tolerance
Snowbrush ceanothus *Ceanothus velutinus*	5	4	5	3
Blueberry elder *Sambucus cerulea*	3	4	3	3
Black greasewood *Sarcobatus vermiculatus vermiculatus*	3	3	3	3
Prostrate kochia *Kochia prostrata*	5	5	4	5
Siberian peashrub *Caragana arborescens*	3	4	3	3
Alkali rubber rabbitbrush *Chrysothamnus nauseosus consimilis*	4	4	5	5
Green rubber rabbitbrush *C. nauseosus graveolens*	4	4	4	4
Russian-olive *Elaeagnus angustifolia*	3	3	3	3
Purple sage *Salvia dorrii carnosa*	4	2	2	2
Big sagebrush *Artemisia tridentata tridentata*	4	3	4	4
Fringe sagebrush *A. frigida*	3	2	3	4
Saskatoon serviceberry *Amelanchier alnifolia*	3	2	3	2
Skunkbush sumac *Rhus trilobata trilobata*	3	3	4	4
Western virginsbower *Clematis ligusticifolia*	4	3	4	4

Source: Adapted from Monsen and Plummer (1978).
[a] 1 = very poor; 2 = poor; 3 = fair; 4 = good; 5 = excellent.

fertilizer treatments. In the western United States studies have been better designed for the comparison of natives and introduced species and have indicated that, while the latter may perform better in the first two years, natives overtake and outperform them. This is important in comparing results from Alberta. Lesko's data, for instance, were only for two years.

On plots treated with combinations of fertilizer, topsoil, and irrigation, introduced and introduced/native mixtures have outperformed native mixes almost without exception. Infrequent superiority of native mixes has usually been related to low precipitation, which may have negated fertilizer effects.

Although some studies show that introduced/native mixes give best results, other research has indicated that such mixes affect the yields of individual species.

In Alaska and similar arctic regions, native species must be carefully matched to site. Commercial (introduced) varieties are more vigourous in the first year (probably due to fertilization). However, native species, once adapted to site, are quite hardy and require no management. It has been stated that established stands of commercial varieties are not a barrier to invasion by native species. However, data indicate that this cannot be accepted as a general rule.

Seed production and seed handling is often a problem with native species.

In the plains area of Alberta, a re-evaluation of roadside plots where natives had been tested showed only cover and nurse crops left.

On well prepared, topsoiled, fertilized, and irrigated plots at Decker, Montana, natives performed quite well or better than expected in the first year (in contrast to mountain tests), although yield of introduced species was better. Yields improved greatly in the second year and natives outperformed agronomics.

At Colstrip, Montana, mixes with introduced species were best in the first year with the all-introduced being the top mix. After four years, a 1/2/1/2 mix was best. Fertilizer greatly affected (increased)

yield of introduced species but had little effect on natives. Introduced species inhibited native species with certain species (Agropyron cristatum and A. elongatum) more dominant than others. Vigourous introduced species decreased stand diversity.

Seed collection and seedling vigour of native species is a problem in this region as well.

Studies that quantitatively or qualitatively compare ative and introduced trees and shrubs are virtually non-existent in the literature. Indications are that natives will outperform introduced species but natives should be adapted to ecozones where they are used. Introduced species have a role to play and should not be ignored.

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SECTION X

ESTABLISHMENT OF GRASSES AND FORBS IN RECLAMATION

31. ESTABLISHMENT OF GRASSES AND FORBS

31.1 DRILLING

Drill seeding, when feasible, may offer a number of advantages depending on seed-bed preparation (Table 31.1), including improved infiltration and moisture storage, some wind protection, more uniform resultant stands, and generally more rapid production of seeded plants (DePuit and Dollhopf 1978). Drilling also requires less seed per unit area than broadcasting (Cook, Hyde and Sims 1974; Schwendiman 1973), seed is covered to a proper depth, seed distribution is uniform and the rate of seeding can be controlled (USDA, Forest Service 1979). Seed may be applied through a mulch cover ensuring contact with soil (DePuit and Dollhopf 1978).

Seed mixtures for reclamation purposes are frequently highly variable in seed size, shape (e.g., awns, bristles), and weight which may cause problems for conventional drilling machinery. Other disadvantages are: (1) single-depth drilling regardless of seed requirements; (2) restriction of machinery to relatively smooth, firm sites with only gradual slopes (less than 3:1); (3) length of time required for seeding; and (4) cost per unit area (DePuit and Dollhopf 1978).

In a summary of methods for reclaiming areas in the north-western U.S., Packer and Aldon (1978) list the Nesbet drill (for sandy soils on gentle slopes), the Nobel drill (for gravelly or rocky sites), the press drill (for plowed or loose seed-beds) and the rangeland disc-drill (for heavy soils previously tilled) as suitable for reclamation work in this region. The rangeland drill can spread lime, fertilizer, and seed in one pass, can be drawn by light-power equipment, and provide a shallow contoured post-seeding surface (Wolcott and Vogel 1975). The feed mechanism on the rangeland drill will not handle seed with large awns or bristles unless modified (Currier 1973). The Truax Native Grass Drill is a modified drill capable of handling bristly native grass seeds (Truax 1979). The Trashy Seed Drill is equipped to handle difficult seed such as Andropogon spp., Bouteloua

Table 31.1. Seeding methods advantages/disadvantages.

Characteristics	Drilling		Broadcasting			
	Machine	Hand	Hydroseeding	Other Machines	Hand	Aerial
Topography	Steep slopes and access are problems; if slopes are greater than 3:1, broadcasting recommended	Less limited	Can handle steep terrain, depending on distance	May be limited by steep terrain	Less limited	Unlimited
Obstructions	Limits use	Unlimited	Unlimited	Somewhat limited	Unlimited	Unlimited
Compacted Soil	Possible	Possible	Not acceptable	Not acceptable	Not acceptable	Not acceptable; soil must be rough enough for wind and rain to cover seeds
Seeding Depth	Variable and controlled	Variable; somewhat less controlled	Lays on top of the soil	No direct control; depends on soil	No direct control	No direct control
Seed size	Variable if drills can be adjusted	Variable if hand-held machines can be adjusted	Small seed	Variable	Variable	Variable
Season	Limited by moisture	Limited by moisture	Limited by low expected moisture	Less limited	Less limited	Less limited
Precipitation	Slightly critical	Slightly critical	Very critical; more success when annual precip. exceeds 12-14 inches.	Very critical	Very critical	Very critical

Continued

Table 31.1. Continued.

Characteristics	Drilling		Broadcasting			
	Machine	Hand	Hydroseeding	Other Machines	Hand	Aerial
Soil Texture	Not critical	Not critical	Critical	Critical	Critical	Critical
Seed Distribution	Uniform	Uniform if person is well trained; seeds can be precisely placed	Less uniform	Less uniform	Not uniform but can be specific to one area	Not uniform
Mulching	Separate treatment	Separate	Same treatment possible but not advised	Separate	Separate	Separate
Cost	Medium	Depends on how many people needed	High	Low	Depends on number of crews needed	Low if surface area to be covered is extensive
Equipment	Special in some cases	Some hand-held equipment available	Scarce Available		Some hand-held equipment available	Various types available; can contracted out
Seed Rate	Less than broadcasting; drastically disturbed sites such as spoils require much heavier seeding rates than do sites where topsoil and some plant cover are intact. Examples: 10-15 lb/acre drilled on north-facing gentle slopes with small grass seed; 25-30 lb/acre if species seed is large; 40-45 lb/acre if conditions are severe, such as southfacing steep slopes	Same as machine drilling	More; as much as double the drilling rate	More	More	More; 1/3 more than drilling

continued

Table 31.1. Concluded.

Characteristics	Drilling			Broadcasting		
	Machine	Hand	Hydroseeding	Other Machines	Hand	Aerial
Trash in Seeds	Must be cleaned from seeds	Must be cleaned from seeds	Cleaning not critical	Cleaning not critical	Cleaning not critical	Cleaning not critical
Time required/ acre to seed	Middle range	High range	Low range	Low range	High range	Lowest

Source: U.S. Forest Service (1979a).

spp., and Cenchrus ciliaris (Currier 1973). A seeder-cultipacker is useful for seeding and packing grasses and legumes and may be used on rough terrain (USDA, Forest Service 1979).

In arid regions of the north-western U.S., good establishment of grasses and legumes was achieved during experiments by drilling seed 10 to 20 mm deep in rows 20 to 40 cm apart in the fall or early spring (Packer and Aldon 1978). For reclamation work in tundra regions, small seeded grasses were best established by drilling no deeper than 6 to 12 mm (Alaska Rural Development Council 1977). A seeding depth of 100 to 150 mm was required to establish grass on steep, eroding, south facing colliery spoil slopes in England (Hackett 1972).

For revegetation of arid regions, seeding rates of 5 to 6 kg/ha for small seeded species on gentle, north facing slopes and 10 to 12 kg/ha for large-seeded species were found suitable by Packer and Aldon (1978) in north-western U.S. studies. On tougher sites, seeding rates should be increased to between 18 and 22 kg/ha.

DePuit and Coenenberg (1979) compared plant establishment by drill seeding and broadcast seeding on topsoiled coal spoils in south-eastern Montana. They found that drill seeding was superior to broadcast seeding for large seeded species when seeding rates were equal. Broadcasting was superior for small seeded species and when seeding rates were double the drilling rates.

Regier (1974) discussed the effects of seeding depth on germination of a grass/legume mix on coal refuse in Blairmore, Alberta. The seed mix consisted of Melilotus sp., Trifolium hybridum, Medicago sativa, Agropyron trachycaulum, A. cristatum, Festuca rubra, Phleum pratense, Bromus sp., Secale cereale, Triticum aestivum, and Hordeum vulgare. Seeding rate for the grass/legume portion was twice the agricultural rate, whereas the cereals were seeded at one-half the agricultural rate. Light and frequent spray irrigations were applied throughout the growing season.

Germination of the grasses and legumes seemed best at seeding depths of 2.5 cm. Cereals germinated well from depths of approximately 10 cm. Fall rye provided the greatest cover after one growing season.

31.2 SPOT SEEDING

Dingle (1973), in a study of erosion prevention in the Swan Hills of Alberta, recommended spot seeding Astragalus cicer, Lotus corniculatus, and Agrostis alba in critical areas. The author noted that this would be very expensive. This seeding method appears to be used very infrequently and is primarily suitable for special situations of small area or for research purposes.

31.3 BROADCAST SEEDING

Broadcast seeding simulates nature's method of dispersal by wind. It may be done by hand, by machine or from the air by planes or helicopters. Broadcasting is faster and cheaper than drilling, provides a more natural looking stand, and when done from the air may be used in areas where access is difficult (Table 31.1) (Plummer 1977; Currier 1973). Broadcasting on a rough seed-bed, followed where possible by harrowing or packing, will provide a better chance for seeds of various sizes (a common feature of reclamation mixes) to be planted at their optimum depth (Plummer 1977).

Drawbacks include a higher seeding rate (usually double the drilling rate), an uneven seed dispersal, poor coverage of seed as compared to drilling, loss of seed to rodents and birds, and generally lower establishment rates (Currier 1973; Schwendiman 1973).

Where possible seed should be applied when windspeed is low to reduce uneven dispersal. Mixing very small, light seeds with sand, clay, fertilizer, or lime may produce a more even seed spread (Schiechtl 1980). Seed should be sown into 5 to 8 cm of loosely packed soil (Currier 1973) and harrowed, packed, or mulched (Schiechtl 1980; Schwendiman 1973) to provide cover for germination.

Broadcasting seed on the ground may be done by rotary spreaders or by seeder boxes. Rotary spreaders rely on the centrifugal force generated by a rotating disc to throw seed. The width of the throw and seeding rate depend on size and weight of the seed, speed of the disc, speed of travel, and wind velocity. Seed is not spread as evenly as from a drill box. The amount of seed is greatest near the

centre of the swath. Seeder boxes simply allow the seed to fall to the ground as the box is pulled or carried by a tractor (Currier 1973). This method provides a much more regulated dispersal of seed.

Aerial seeding is advantageous where the terrain is too rough to use land-going equipment. Often these sites can be roughened, by the use of a chain for example, but not tilled enough to allow a drill to go over the site. Aerial seeding also allows flexibility of scheduling among sites, and it can be used in situations where the vegetation specialist wants to introduce some additional species into the area without disturbing the vegetation currently growing on the site (USDA, Forest Service 1979).

Aircraft are best suited for seeding large, gently sloping, and elongated areas such as pipeline rights of way and roadsides. Ritchie and Davis (1978) compared seeding rates from small fixed-wing aircraft and a DC-3 in mountainous terrain. The small aircraft carried a payload of between 0.5 and 1 t of seed and showed a considerable variation in seed delivery. The DC-3 carried a 4.5 t payload, spent less time in the air relative to the amount of seed spread, and provided as good or better seed delivery. Weston (1973) found that aircraft seeding gave a more even distribution of seed than either ground seeding or hydroseeding when revegetating mine tailings ponds.

Aircraft should be flown low to reduce loss of seed and minimize the separation of heavy from lighter seed types (Langevin and Lulman 1977). The following formula may be used to determine the seeding rate obtained from an aircraft (Currier 1973):

$$R = \frac{P}{.002 \times S \times W}$$

where

R = kg/ha desired on ground

P = kg/minute from aircraft

S = aircraft speed

W = swath width

.002 = a constant

Aircraft should be equipped with a power-driven, seed metering device. An adjustable opening which allows seed to fall by gravity is not suitable when a mixture of various seed sizes and weights is being used (Currier 1973).

Dingle (1973) compared helicopter seeding with that obtained by ground-crews and found the former far more efficient. He found up to three times the coverage on steep slopes or bare areas using the helicopter. Helicopters are better suited to rough terrain and small areas with difficult access. Because helicopters can adjust to changes in terrain faster than airplanes and because of the downdraft of the rotor, uniform seed distribution is more easily obtained than with an airplane (Schwendiman 1973).

Ritchie and Davis (1978) studied the seed distribution obtained from helicopter sowing using a simple disc spinner and a turbine spinner. The turbine spinner provided a wider, more even swath (10 m) than that of the disc (5 m) (Figure 31.1). At an airspeed of 64 km/h, the seeding rates were 50 and 25 kg/ha for disc and turbine spinners, respectively. Seeding rates for a third applicator, the "Transland Sling King", were 240 kg/ha over a 10 m swath when fully open and 25 kg/ha over an 8 m swath when half opened (Figure 31.1). When fully opened, the "Sling King" spread seed at a grossly excessive rate.

The effective spread widths for seed and fertilizer when applied from a "Sling King" bucket spreader suspended from a Bell 206 helicopter were assessed by Younkin and Martens (1976). Tests were carried out near Swimming Point, N.W.T. (grass) and Inuvik, N.W.T. (fertilizer).

To determine spread width for a seed mixture, twenty-eight greenhouse flats (52 x 25.5 cm) partially filled with water were set out on the soil surface in four transects of 7 flats, each 18 m long and 30 m apart. A single pass was made across these flats with the helicopter and "Sling King" seed spreader. Wind speeds of 8 to 12 km/h across the flight path were compensated for by making the pass approximately 3.5 m to the windward side of the centre path (i.e., directly over quadrat 3; Table 31.2). The altitude of the seed bucket

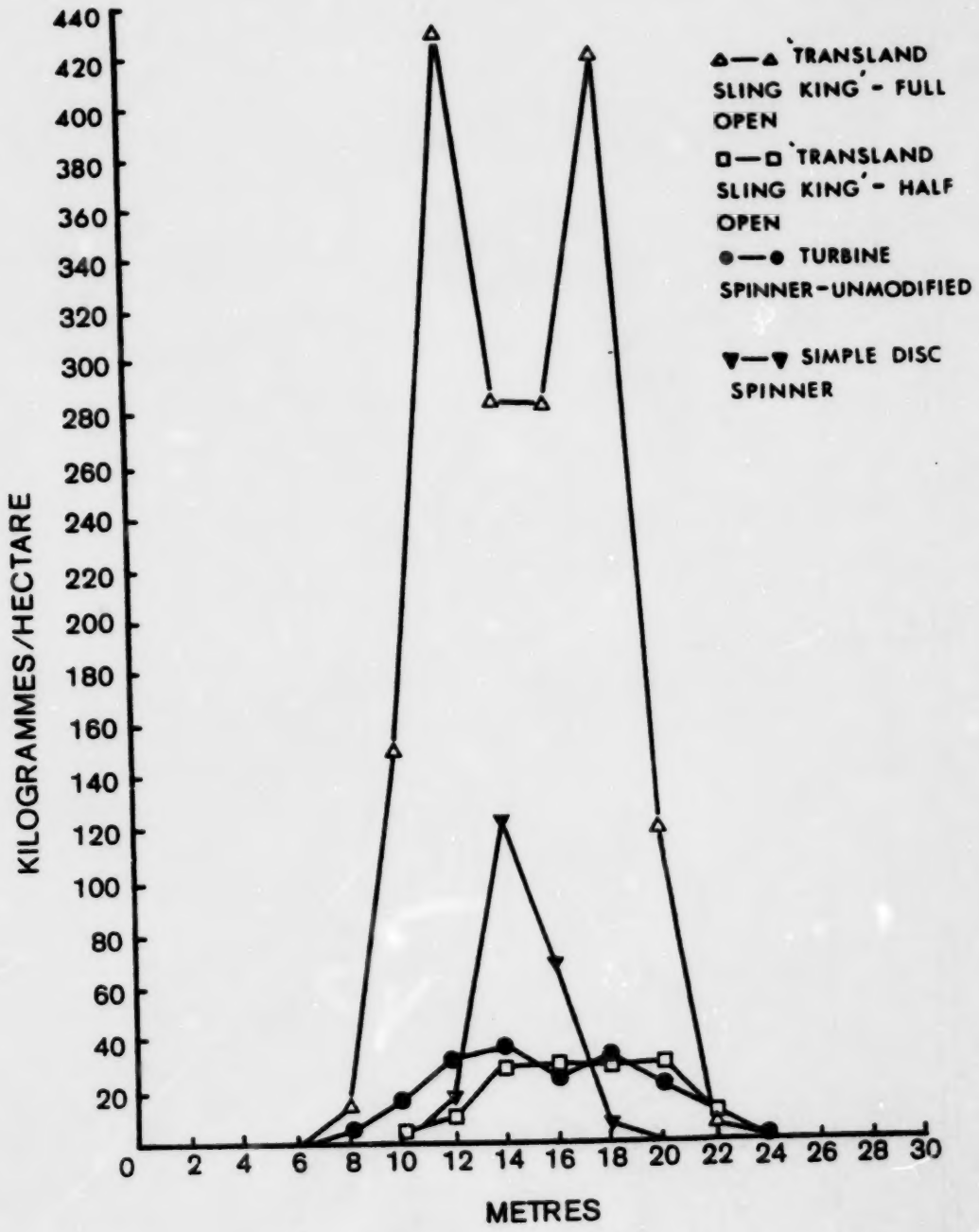

Figure 31.1. Distribution of seed from helicopter operated rotary applications.

Source: Ritchie and Davis (1978)

Table 31.2. Distribution of a seed mix and its component species (kg/ha) following a single pass of the seed bucket, Inuvik, N.W.T.

Transect	Seed	Quadrat 1	2	3	4	5	6	7
I	NKB[a]	0.00	1.40	19.00	10.00	0.03	0.04	0.01
	CRF	0.00	30.30	20.00	18.70	0.09	0.00	0.00
	Total Mix	0.00	31.70	39.00	28.70	0.12	0.04	0.01
II	NKB	0.00	0.13	25.10	14.20	0.07	0.01	0.00
	CRF	0.00	21.20	19.50	7.50	0.20	0.00	0.00
	Total Mix	0.00	21.33	44.60	21.70	0.27	0.01	0.00
III	NKB	0.00	0.00	39.10	12.40	0.10	0.03	0.01
	CRF	0.09	7.20	20.00	11.00	3.00	0.00	0.00
	Total Mix	0.09	7.20	59.10	23.40	3.20	0.03	0.01
IV	NKB	0.00	0.00	22.20	2.10	1.00	0.01	0.01
	CRF	0.09	4.40	12.30	2.60	1.80	0.00	0.00
	Total Mix	0.09	4.40	34.50	4.70	2.80	0.01	0.01

[b] Flight path

Source: Adapted from Younkin and Martens (1976).

[a] NKB = Nugget Kentucky bluegrass
CRF = creeping red fescue
Mix = 1:1 mix of above species

was 15 m and the helicopter speed 48 km/h. The flow rate of the bucket was adjusted to 41 kg/min. The seed used was a 1:1 mixture (by weight) of Poa pratensis cv. Nugget and Festuca rubra cv. Arctared. The Festuca is a relatively large seed having approximately 1355 seeds/g while the Poa is much smaller, having 4750 seeds/g. After the pass, the seed was collected from each flat, dried, separated according to species, weighed, and counted.

During the fertilizer test, greenhouse flats without water were set out as described above. Wind speed and direction were similar and were compensated for by making the pass approximately 3 m to the windward side of the centre path. The altitude of the seed bucket was 15 m but the helicopter speed increased to 80 km/h. The flow rate of the bucket was adjusted to deliver fertilizer (14-28-14 in pellet form) at 150 kg/min. After a single pass the fertilizer was collected from each pan and weighed.

The seed mix application was highest in the quadrats directly under the flight path, dropping off rapidly to either side (Table 31.2). At most, the effective spread distance was 9 m, a 41 kg/min flow rate applying seed at 39 kg/ha in quadrat 3, 28.7 kg/ha in quadrat 4, and 31.7 kg/ha in quadrat 2. Other quadrats received only very light seed application. Transects 3 and 4 received a much narrower seed distribution pattern than transects 1 and 2.

The distribution of the species in the mixture was dependent upon seed weight and wind direction. The very light P. pratensis was mainly deposited in quadrat 3 with the remainder of the quadrats in the windward direction receiving a very light seeding. The heavier F. rubra had a more even distribution with most of the seed being in quadrats 2, 3, and 4.

In comparison to the seed mix, the fertilizer had a wider and more even distribution (Table 31.3). The effective spread width of fertilizer on a single pass was 12 m, a 150 kg/min flow rate applying a mean of 26, 60, 51, 40, and 29 kg/ha, respectively, in quadrats 2 to 6. However, fertilizer was collected in decreased quantities on either side of the effective spread width. Therefore, on an operational scale,

Table 31.3. Fertilizer distribution (kg/ha) following a single pass of a seed bucket, Inuvik, N.W.T.

Transect	Quadrat						
	1	2	3	4	5	6	7
I	8	22	44	38	41	27	9
II	9	14	64	47	36	24	14
III	18	44	76	56	32	21	11
IV	20	22	53	62	52	45	15
Mean	16	26	60	51	40	29	12

Source: Younkin and Martens (1976b).

overlapping of application would occur on adjacent passes. When overlap at a 12 m flight path spacing is accounted for, mean application rates would be 52, 76, 51, 52, and 58 kg/ha, and at a 15 m spacing 42, 55, 56, 46, 44, and 42 kg/ha.

Wind direction also affected fertilizer distribution. Using the flight path as a reference, fertilizer was deposited roughly twice as far downwind as upwind.

Langevin and Lulman (1977) have reported on the first-year results of a revegetation program at the Syncrude operation in the Athabasca oil sands area. Three seed mixtures were applied using aerial seeding, hydroseeding or hand broadcasting. Seventy-two hectares were seeded at 100 to 117 kg/ha using a Bell 206B helicopter equipped with a 450 kg capacity Simplex powered bucket. The helicopter was flown an average of 12 m above the ground at 72 km/h. Sixty-two hectares were seeded at 112 kg/ha using a Bowie truck mounted hydroseeder with a delivery pressure of 2756 kPa. Small, hand-held cyclone seeders were used to broadcast seed in small areas at 84 to 112 kg/ha.

For aerial seeding, all leguminous seed was pre-inoculated with double quantities of nitra coat and Rhizobium bacteria. The seed used in the hydroseeder was not pre-inoculated, but 10 times normal inocula was added to the hydroseeder tank and applied in the slurry with the seed. Langevin and Lulman did not state if inoculum was added to the broadcast seed.

Data on percent cover and plant dry matter production were presented for 18 plots. Phleum pratense and Calamagrostis canadensis were the most successful grasses. The success of legumes was variable with better results from aerial seeding than hydroseeding. The legume seed was not necessarily distributed on the ground close to the inoculum which may account for the poor response of hydroseeded legumes. High inoculation rates (perhaps up to 20 times normal) might counteract the tendency of hydroseeded legumes to be separated from the inoculum.

Langevin and Lulman (1977) cited access during wet spring conditions, cost per hectare, and ability to reach widely dispersed sites within a short time as advantages of aerial seeding. Infrequent

suitable weather conditions and control of seed dispersal were disadvantages, the latter because the pilot may not have adequate knowledge of seeding requirements. Best germination and growth was achieved on wet, muddy land because seed is impelled into the soil. Seed falling on dry, compacted surfaces is often lost to wind or birds and may dry out before establishment can take place. Hand-broadcast techniques offered an opportunity to seed and fertilize small, otherwise inaccessible areas with good regulation of seed distribution and economy of seed and fertilizer. Seed-bed preparation was critical for this operation. Without large mechanical cyclones, this was a labour intensive method and inappropriate for large areas.

Data from the first two growing seasons of an experiment using native seeds to reclaim a south-eastern Montana coal mine were reported by DePuit and Coenenberg (1979). Thirty-eight centimetres of sandy loam was applied as topsoil and the plots were chisel plowed to 30 cm producing a loose, moderately rough seed-bed. Fertilizer (16-20-0) was applied at a rate of 185 kg/ha to the plots providing 39.6 kg/ha actual N and 16.3 kg/ha actual P.

Three sets of variables were tested in the study as follows:

1. Seeding Mixture. Mixture 1 with 9 perennial grass and shrub species; Mixture 2 with 13 perennial grass species; Mixture 3 with 19 perennial grass species. A uniform mix of 9 native forb species was also seeded with each of Mixture 1 through 3 (see Table 31.4). Selection of species/varieties seeded was based upon adaptation to local environmental conditions (i.e., abundance in local plant communities) and/or degree of previous success in mined land seeding trials in the region.
2. Seeding Method. Drill seeding (at 2.5 cm depth) with rangeland drill versus broadcast seeding. Broadcast seeded plots were cultipacked following seeding.
3. Seeding Rate. Three seeding rates for each seeding method. For drill seeding, Rate 1 was 28 kg P.L.S. (pure

Table 31.4. Seed mixture information, native species mixture establishment study, Colstrip, Montana, 1977.

Plant Type [a]	Scientific Name	Common Name	Seed Source or Selection	Actual Bulk Drill Seeding Rates in Kg/ha [b] (numbers in parentheses = PLS seeding rates, where calculable)								
				Seeding Mixture 1			Seeding Mixture 2			Seeding Mixture 3		
				Drill Rate 1	Drill Rate 2	Drill Rate 3	Drill Rate 1	Drill Rate 2	Drill Rate 3	Drill Rate 1	Drill Rate 2	Drill Rate 3
CSPG	*Agropyron dasystachyum*	Thickspike wheatgrass	Critana	3.1(2.7)	4.6(4.0)	6.3(5.4)	1.9(1.7)	2.8(2.5)	3.8(3.4)	1.3(1.2)	2.0(1.8)	2.7(2.5)
CSPG	*Agropyron riparium*	Streambank wheatgrass	Sodar				1.7(1.3)	2.5(2.0)	3.4(2.7)	1.2(1.0)	1.8(1.5)	2.5(2.0)
CSPG	*Agropyron smithii*	Western wheatgrass	Rosanna	4.6(3.7)	6.8(5.5)	9.2(7.4)	2.8(2.2)	4.1(3.4)	5.6(4.5)	1.9(1.6)	2.8(2.4)	3.8(3.1)
WSPG	*Bouteloua curtipendula*	Sideoats grama	Pierre				6.1(1.1)	9.0(2.0)	12.1(2.7)	4.4(1.0)	6.5(1.5)	8.7(2.0)
WSPG	*Calamovilfa longifolia*	Prairie sandreed	Goshen	2.1(1.7)	3.1(2.5)	4.3(3.4)	1.2(1.0)	1.8(1.5)	2.5(2.0)	0.9(0.8)	1.3(1.1)	1.8(1.6)
CSPG	*Agropyron inerme*	Beardless wheatgrass	Whitmer							1.9(1.2)	2.8(1.8)	3.8(2.5)
CSPG	*Agropyron trachycaulum*	Slender wheatgrass	Alberta							1.6(1.6)	2.4(2.4)	3.1(3.0)
CSPG	*Oryzopsis hymenoides*	Indian ricegrass	Paloma	3.1(2.5)	4.6(3.7)	6.3(4.9)	1.9(1.5)	2.8(2.1)	3.8(2.9)	1.3(1.1)	2.0(1.7)	2.7(2.2)
CSPG	*Poa compressa*	Canada bluegrass	Reubens	0.7(0.6)	1.0(0.8)	1.3(1.1)	0.4(0.3)	0.7(0.4)	0.9(0.7)	0.3(0.2)	0.4(0.3)	0.7(0.4)
WSPG	*Andropogon hallii*	Sand bluestem	N. Dakota				1.3(0.8)	2.0(1.1)	2.7(1.6)	1.0(0.5)	1.5(0.8)	2.0(1.1)
WSPG	*Schizachyrium scoparium*	Little bluestem	Blaze							2.1(1.2)	3.1(1.8)	4.3(2.5)
WSPG	*Sporobolus cryptandrus*	Sand dropseed	Colorado							0.7(0.3)	1.0(0.4)	1.3(0.7)
CSPG	*Stipa viridula*	Green needlegrass	Lodorm	5.3(2.7)	7.8(4.0)	10.5(5.4)	3.1(1.7)	4.6(2.5)	6.3(3.4)	2.2(1.1)	3.4(1.7)	4.5(2.2)
S	*Artemisia ludoviciana*	Cudweed sagewort	S. Idaho	0.2	0.3	0.4	0.1	0.2	0.2	0.1	0.1	0.2
S	*Artemisia cana*	Silver sagebrush	E. Montana				0.2	0.3	0.4	0.1	0.2	0.2
S	*Atriplex canescens*	Fourwing saltbush	Wyoming	6.7	10.0	13.5	3.9	5.8	7.8	2.8	4.1	5.6
S	*Chrysothamnus nauseosus*	Rubber rabbitbrush	E. Montana							0.3	0.4	0.7
S	*Rosa woodsii*	Woods rose	E. Montana							0.9	1.3	1.8
S	*Amorpha canescens*	Lead plant	Idaho	0.3	0.4	0.7	0.2	0.3	0.4	0.1	0.2	0.2
F	*Helianthus annuus*	Annual sunflower	S. Idaho	0.2	0.3	0.4	0.2	0.3	0.4	0.2	0.3	0.4
F	*Balsamorhiza sagittata*	Arrowleaf balsamroot	S. Idaho	0.2	0.3	0.4	0.2	0.3	0.4	0.2	0.3	0.4
F	*Echinacea angustifolia*	Black samson	E. Montana	0.2	0.3	0.4	0.2	0.3	0.4	0.2	0.3	0.4
F	*Helianthus rigida*	Stiff sunflower	E. Montana	0.2	0.3	0.4	0.1	0.2	0.2	0.1	0.2	0.2
LF	*Thermopsis montana*	Montana thermopsis	Idaho	0.2	0.3	0.4	0.2	0.3	0.4	0.2	0.3	0.4
F	*Linum lewisii*	Lewis flax	E. Montana	0.1	0.2	0.2	0.1	0.1	0.2	0.1	0.1	0.2
LF	*Petalostemum purpureum*	Purple prairieclover	E. Montana	0.2	0.3	0.4	0.2	0.3	0.4	0.2	0.3	0.4
F	*Ratibida columnifera*	Prairie coneflower	E. Montana	0.2	0.3	0.4	0.2	0.3	0.4	0.2	0.3	0.4
F	*Achillea millefolium*	Western yarrow	S. Idaho	0.1	0.1	0.2	0.1	0.1	0.2	0.1	0.1	0.2

Source: DePuit and Coenenberg (1979)

a CSPG = cool season perennial grass; WSPG = warm season perennial grass; S = shrub or half-shrub; F = forb; LF = forb (legume)

b Broadcast seeding rates for each mixture-rate combination are twice the given drill seeding rates

live seed) per ha. Rate 2 was 42 kg P.L.S. per ha, and Rate 3 was 56 kg P.L.S. per ha. By convention, the three broadcast seeding rates were double the drill rates (i.e., 56, 84, and 112 kg P.L.S. per ha, respectively).

For the sake of brevity DePuit and Coenenberg (1979) have presented the data from the second growing season (1978) as averages of experimental treatments. They stressed that data and trends were preliminary findings only.

Table 31.5 (A) shows that broadcast seeding was superior to drill seeding in terms of perennial grass production, stand composition, and species diversity. Nearly all species performed better under broadcast seeding (mean rate = 82 kg/ha) than under drill seeding (mean rate = 42 kg/ha). When drilling and broadcast seeding are compared at equal rates (56 kg/ha), however, perennial grass production was higher under drill seeding (Table 31.5, B). This was primarily due to the increased growth of the larger seeded species (e.g., Agropyron dasystachyum, A. riparium, A. smithii, and A. trachycaulum). They pointed out, however, that the smaller seeded grasses consistently performed better when broadcast seeded. Although productivity was greater under drill seeding, stand composition and diversity were greater under broadcast seeding. This may be a result of the variable seed depths available when broadcasting into a moderately rough seed-bed.

Table 27.2 (B) shows the effects of mean seeding rates on vegetation establishment. Productivity of perennial grasses increased from Rate 1 to Rate 2, but only slightly from Rate 2 to Rate 3. This suggested that although some stimulation of growth over 56 kg/ha (Rate 2) occurred, the increase may not be proportional to the increased cost. Canopy cover data (Table 27.2, B) show that individual species vary in their response to increased seeding rates. Agropyron dasystachyum, A. riparium, and Bouteloua curtipendula increased with increasing seed rates while A. inerme, Andropogon hallii, Calamovilfa longifolia, and Poa compressa decreased. In addition, plant community diversity decreased with increasing seed rates.

Table 31.5. Effects of seeding method on stand aerial biomass, seeded species canopy cover, stand composition and diversity, native species establishment study, Colstrip, Montana, 1978 (second growing season).

	A. Mean of All		B. Means of All Plots At Equal[f] Seeding Rates Under:	
	Drill Seeded Plots[d]	Broadcast Seeded Plots[e]	Drill Seeding	Broadcast Seeding
Aerial Biomass (kg/ha) for:				
Perennial grasses	1262.4	1484.8	1537.5	1228.7
Annual grasses	65.1	28.2	76.5	32.8
Legumes	445.0	481.4	387.9	456.9
Forbs[a]	57.5	34.4	39.1	35.6
Shrubs	355.9	346.1	352.3	435.1
Russian thistle	118.3	60.4	109.5	48.3
Total aerial biomass	2304.2	2435.3	2502.8	2237.4
Canopy Cover (%) for Seeded Species:				
Critana thickspike & Sodar Streambank Wheatgrasses[b]	30.1	34.8	34.6	28.0
Whitmar Beardless Wheatgrass	0.3	0.2	0.2	0.3
Rosanna Western Wheatgrass	15.8	17.5	16.5	13.8
Slender Wheatgrass	9.5	10.3	10.4	8.4
Sand Bluestem	0.2	0.2	-	0.3
Pierre Sideoats Grama	0.3	0.7	0.3	0.4
Goshen Prairie Sandreed	0.4	0.7	-	1.7
Paloma Indian Ricegrass	4.2	5.4	2.9	6.2
Reubens Canada Bluegrass	0.2	0.5	0.2	0.6

continued...

Table 31.5. Continued.

	A. Mean of All		B. Means of All Plots At Equal[f] Seeding Rates Under:	
	Drill Seeded Plots[d]	Broadcast Seeded Plots[e]	Drill Seeding	Broadcast Seeding
Blaze Little Bluestem	-	T[g]	-	T
Sand Dropseed	-	T	-	T
Lodorm Green Needlegrass	6.7	9.6	4.0	9.6
Purple Prairieclover	0.1	0.1	T	0.1
Western Yarrow	-	0.1	-	0.3
Sunflower	0.1	0.3	0.1	0.5
Lewis Flax	0.7	0.8	1.8	1.9
Prairie Coneflower	T	0.1	T	T
Silver Sagebrush	-	T	-	T
Cudweed (Louisiana) Sagewort	-	T	-	T
Fourwing Saltbush	16.0	15.5	15.4	19.5
Rubber Rabbitbrush	-	T	-	T
% Stand Composition of Seeded Native Species[c]	74.5	82.6	72.0	85.6
Shannon-Weaver Function Diversity Index for Seeded Native Species	0.75782	0.79094	0.71450	0.84068

continued...

Table 31.5. Concluded.

	A. Mean of All		B. Means of All Plots At Equal[f] Seeding Rates Under:	
	Drill Seeded Plots[d]	Broadcast Seeded Plots[e]	Drill Seeding	Broadcast Seeding
Shannon-Weaver Function Diversity Index for Entire Stand	0.91495	0.91740	0.85077	0.96643

Source: DePuit and Coenenberg (1979b:79)

[a] Excluding Russian Thistle

[b] Field differentiation of these two species impossible in 1978; many taxonomists combine these species

[c] Based upon canopy cover

[d] At average seeding rate of 42 kg P.L.S./ha

[e] At average seeding rate of 84 kg P.L.S./ha

[f] 56 Kg P.L.S./ha

[g] T = trace (<0.1% cover)

The authors concluded that results indicated little benefit in seeding rates above 56 kg/ha. They also noted, however, that seeding rates were intentionally heavy based on previous reclamation experience, and that further studies at lower rates were warranted. Boutilier and Morton (1978), in a study on seeding rates for revegetating coal spoils in Nova Scotia also suggested that 56 kg/ha should be used as the "general purpose seeding rate". They noted that a higher seeding rate (112 kg/ha) should be used when fertilizer input is low. Brown et al. (1976) had some success seeding alpine areas at between 28 and 56 kg/ha in late fall but noted that higher seeding rates may be necessary on steep slopes. Walker, Sadasivaiah and Weijer (1977) seeded several species of Agropyron in alpine areas in Alberta at rates of 13 to 29 kg/ha. Success was extremely poor and the authors suggested rates up to 56 kg/ha may be needed on steep slopes. The British Columbia Ministry of Energy, Mines and Petroleum Resources (1978) recommended the use of 56 kg/ha in alpine areas and 22.4 to 44.8 kg/ha in forested areas. Kay (1973) also recommended at least 56 kg/ha for revegetating areas above 914 m.

Cook, Hyde and Sims (1974), among others, strongly advocate the use of drill seeding over broadcast seeding where the former is practical. Initial results of their study concur with this only if equal seeding rates are considered. DePuit and Coenenberg (1979) noted that if establishment of a diverse community is the desired goal, then broadcast seeding at double the drilling seed rate into a rough seed-bed will, in many cases, be superior to conventional drilling techniques.

31.4 HYDROSEEDING

Hydroseeding or hydraulic seeding is the application of a slurry of seed and water to soil. The slurry may also contain sprigs, wood-fibre, neutralizing agents (lime), and fertilizer (hydromulching). Slurries should not contain more than 224 kg of seed or solids per 455 L of water. This is the upper limit and much too thick to get even distribution of the slurry; 112 to 168 kg of solids per 454.6 L of water is much better (Alaska Rural Development Council 1977; Schwendiman

1973). The slurry pump should be capable of passing 2.5 cm solids (Habeck and Staft 1975). The mixture must be constantly agitated to ensure an even consistency (Schiechtl 1980).

Hydromulching is an excellent method of applying seed and fertilizers to steep areas where the wood-fibre holds the seed and fertilizer in position. On short or gentle slopes the fibre also provides protection against erosion until the vegetation is established. Other advantages (Table 31.1) include seeding areas too wet to access with equipment, avoidance of planting very small seeds too deep, and a very even distribution of seed (Kay 1976). However, Stephenson (1974) has pointed out that high winds in mountain areas make an even distribution of seed extemely difficult to achieve. A major disadvantage is the high cost compared to conventional seeding methods.

Hydroseeders can spray slurry up to 61 m under calm conditions (Person 1978; Habeck and Staff 1975). Habeck and Staff (1975) noted that a hydroseeder can spray up to 1.2 ha in 15 min while Person (1978) described a 13 638 L machine which can cover 4.1 ha in 30 min. Schiechtl (1980) advocated spraying 0.2 to 2 cm thick slurry layers. On rocky areas this layer should be thicker and may require two or more applications. He noted that anywhere from one to 30 L of slurry may be required per square metre.

Kay (1976:1) pointed out that "hydroseeding and the associated materials advertised as controlling erosion or assisting in plant establishment are not substitutes for sound engineering and agriculture, and must be used correctly to be of value...."

Kay (1976, 1977) reported on two experiments to determine the effects of seed residence time in a hydroseeder on germination and legume inoculation. In the first test, seed of Agropyron tricophorum cv. Topar was circulated continuously in three different hydroseeders for up to 120 min. Four seed lots of 50 seeds each were removed from the hydroseeder at 1, 10, 20, 30, 60, and 120 min and were germinated at room temperature. Tests were conducted with and without wood fibre at 6 kg/L.

Machine No. 1 used an 8 x 8 cm Gorman-Rupp self-priming centrifugal pump (Model 12 D1). The slurry was agitated by bypassing it through this pump back to the main holding tank. This involved constant recycling of the slurry. Machine No. 2 used a gear pump with rubber-covered gears (Model 2500/1B Bowie) and agitation by paddle only. Thus, the slurry went through the pump only once, and much more slowly than in Machine No. 1. Machine No. 3 used a centrifugal pump (Morris) agitated both by a paddle and by recirculating through the pump, but because of the paddle the seed was not passed through the pump as many times as in Machine No. 1.

Figure 31.2 shows the effects of time spent in the various hydroseeders on germination.

Based on this data, Kay (1976:10) suggested that the following precautions should be taken:

"1. One solution is to use a gear pump with paddle agitation. However, most hydroseeders utilize a centrifugal pump. If a centrifugal pump is used, limit the delivery time (moment from placing seed in water until tank is empty) to 20 minutes or less, and use fiber to protect the seed (500 lb/1500 gal water)[0.04 kg/L]." Hodder (1970) found the greatest seed damage with large seeded species or with seeds which had large lemmas and paleas.

2. Put seed into slurry just before the start of seeding, allowing only time for adequate mixing. Sheldon and Bradshaw (1977) and Bengston, Mays and Zarger (1971) found that when seeds were mixed with fertilizer for any length of time osmotic effects on the seeds occurred, impairing germination, particularly where rye is a component. Hodder (1970) found that fertilizer slurries may inhibit normal germination or development of roots and shoots.

3. "In seeding loose soils on benches or slopes where the seed would cover naturally, or on straw-mulched areas, consider broadcasting the seed by hand or

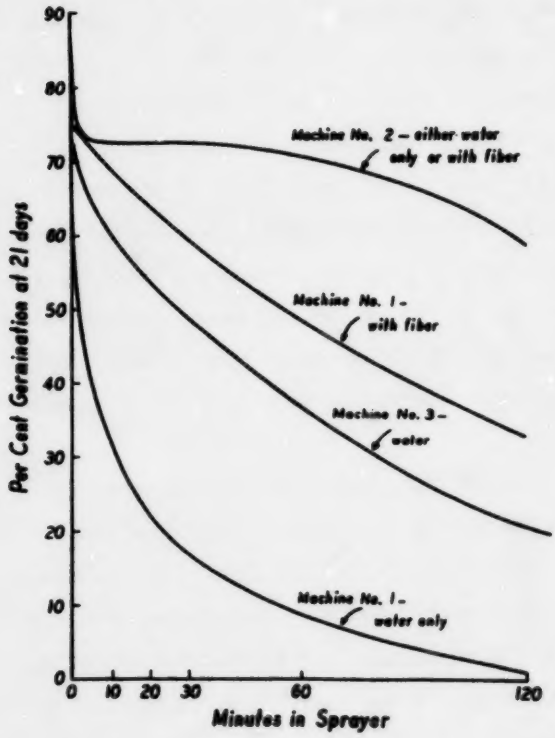

Figure 31.2. Effect of time and wood fiber on seed germination of Topar pubescent wheatgrass planted by hydroseeding.

Source: Kay (1976).

'belly-grinder', or even by aircraft on larger jobs. Fiber can be applied over seed with either pump if a mulch effect is [needed]...."

Kay (1976), Schwendiman (1973), and Bengtson, Mays and Zarger (1971) suggested spraying seed and fertilizer initially to ensure seed contact with the soil and then mulching afterwards. Gallup (1974) and Currier (1973) noted that 60 to 70% of seed gets hung up in the mulch and has little or no chance to root in the mineral soil.

In the second test, seeds of two cultivars of Trifolium subterraneum were pellet-inoculated with the appropriate Rhizobium bacteria at four times the recommended rate, allowed to cure overnight, and then circulated for up to 120 min in a Gorman-Rupp hydroseeder (for description see Machine No. 1 in previous experiment). The slurry consisted of 569 L of water, 22.7 kg wood-fibre, 15.9 kg of treble superphosphate fortified with elemental sulfur (0-35-0-20) and 0.9 kg of clover seed.

After 1, 10, 20, 30, 60, and 120 min samples of the slurry were hydroseeded onto a prepared seed-bed. Application rates per ha were 980 kg wood-fibre, 685.4 kg 0-35-0-20 fertilizer, and 39.2 kg of seed. These were compared against pellet-inoculated seeds dry broadcast at 22.4 kg/ha and uninoculated seeds dry broadcast at 22 kg/ha. All plots were seeded 01 October 1971 and evaluated 02 March 1972.

Table 31.6 shows the effects of time spent in the hydroseeder on the inoculation status of the legumes. Kay concluded that pellet-inoculated T. subterraneum seed will remain effectively inoculated in a hydromulching slurry if delivery time is limited to 30 min or less with a centrifugal pump, and probably longer with a rubber-covered gear pump. Pellet-inoculated broadcast seeds were just as successful as seeds which had remained in the hydroseeder less than 60 min. The uninoculated seed and the seed which had remained in the hydroseeder for 120 min showed the lowest inoculation levels in the field. In later experiments, however, Kay (personal communication 1983) was unable to reproduce these results and has therefore altered his recommendations for seeding of legumes to dry spreading only. He noted that water slurries tended to

Table 31.6. Effect of hydroseeder on subclover inoculation (10 is excellent inoculation, 1 is none).

Treatment	Mt. Barker[a]	Woogenellup[a]
1 minute	10a	9a
10 minutes	9a	9a
20 minutes	8a	8a
30 minutes	8a	8a
60 minutes	4b	8a
120 minutes	1c	2b
Dry pellet	8a	8a
No inoculation	1c	1b

Source: Kay (1976).

Note: Values followed by the same letter are not significantly different at the 0.01 level.

[a] Cultivars of subclover (Trifolium subterraneum L.)

wash the Rhizobium off the seed, thus reducing inoculation effectiveness.

Two mixtures of grass and legumes were hydroseeded on four different slopes of 25- to 30-year-old sandstone and shale overburden at the Luscar Mine, 40 km south of Hinton, Alberta (Etter 1971). The two seed mixes (Table 31.7) were in a slurry comprised of: water (955 L/ha), air-dried cellulose fibre mulch (896 to 1120 kg/ha), 10-30-10 fertilizer (224 kg/ha), 46-0-0 urea (112 kg/ha), and activated sewage organic fertilizer (224 kg/ha). The slurry was applied in the fall (23 September 1970) and the spring (27 May 1971) on south-east to east facing slopes of 0 to 6%, 13 to 21%, 33 to 39% and 70 to 76%.

Plant density counts showed that under the most favourable conditions, only 10% of the maximum number of germinants was obtained. Plant density was greatest on the 0 to 6% slope and least on the 70 to 76% slope (Table 21.1). The densities obtained on 0 to 6%, 13 to 21%, and 33 to 39% slopes were considered adequate for erosion control.

A second series of revegetation studies at the Luscar Mine were reported by Lesko, Etter and Dillon (1975). Experiments were carried out at two locations. The first was 20-year-old sandstone and shale overburden and the second was a recent, mostly shale, spoil with a south-west aspect and 10 to 20% slopes.

The first experiment was conducted to test the effect of seeding time and slope on the establishment of 34 plant species. Five seed mixtures were hydroseeded on four slope gradients (0 to 6%, 13 to 21%, 33 to 39%, and 70 to 76%) at a rate of 112 kg/ha. The hydroseeding slurry contained: water (1.1 L/m^2), wood-fibre (90 to 110 g/m^2) 10-30-10 fertilizer (22.59 g/m^2), 46-0-0 urea (11.00 g/m^2), and activated sewage (22.59 g/m^2). Five plots were seeded 23 September 1970 and five on 27 May 1971. The establishment of grasses and legumes decreased markedly with increasing slope (Figure 31.3).

In the second experiment the effects of slurry mixes b to e (Table 31.8) were tested on four rough-graded plots with a seed mixture containing Agropyron latiglume and two shrubs. Seeds were sprayed on with water, in May 1972, and then the different slurry mixes were

Table 31.7. Composition of two seed mixes used at Luscar mine, Alberta.

Mix I		Mix II	
Species	Seeding Rate (kg/ha)	Species	Seeding Rate (kg/ha)
Agropyron cristatum	33.6	Agropyron riparium	13.4
Agrostis alba	11.2	Bromus inermis	16.8
Festuca rubra	33.6	Elymus junceus	16.8
Poa pratensis	11.2	Phleum pratense	16.8
Melilotus alba	22.4	Medicago sativa	16.8
Total	112	Total	80.6

Source: Adapted from Etter (1971).

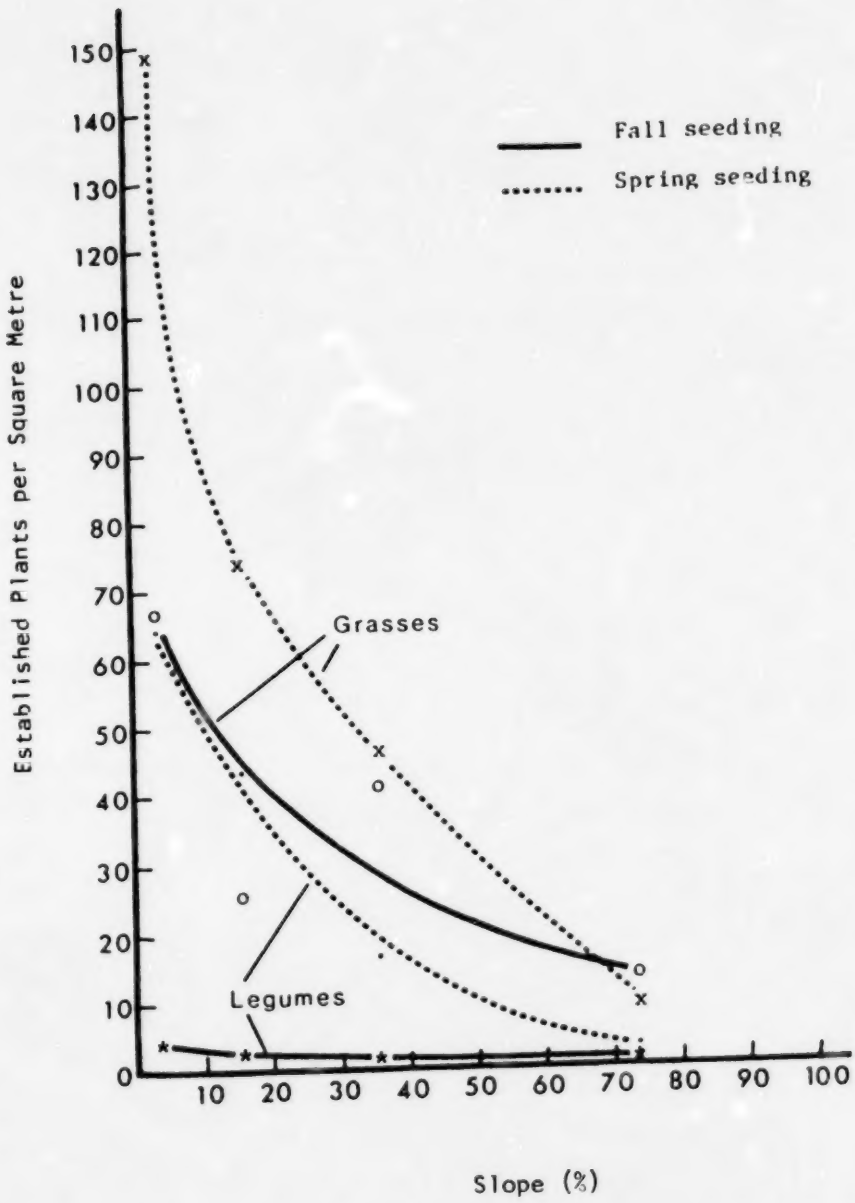

Figure 31.3 The effect of slope and seeding time on seedling establishment, one growing season after seeding at the Luscar Mine, Hinton, Alberta.

Source: Lesko, Etter and Dillon (1975:35)

Table 31.8. Slurry mixes used in the seeding experiments at Luscar Mine, Alberta.

Ingredients	Slurry a	Slurry b	Slurry c	Slurry d	Slurry e
Water (L/m^2)[a]	3.76	3.76	3.76	3.76	3.76
Wood Fiber Mulch (g/m^2)[b]	218.67	218.67	218.67	-	54.67
Waste paper (g/m^2)	-	-	-	-	164.00 to 196.81
Fertilizer (g/m^2)					
10 - 30 - 10 & organic	22.59	22.59	22.59	22.59	22.59
46 - 0 - 0	11.02	11.02	11.02	11.02	11.02
Adhesive AK (L/m^2)	0.06	-	0.06	-	0.06
Conditioner (g/m^2)	-	-	2.47	-	-

Source: Lesko, Etter, and Dillon (1975).
[a] gal/acre = liters/m^2 x 890.21
[b] lb/acre = g/m^2 x 8.93

applied to cover the seeds. The use of four slurry mixes did not produce significant differences in plant establishment.

31.5 SUMMARY

Drill seeding, broadcast seeding, hydroseeding, and spot seeding are available for controlled seed dissemination on reclamation areas. Spot seeding is frequently used for very specific problem areas or in research.

Advantages of drill seeding are: (1) improved moisture storage; (2) more uniform stands; (3) wind protection for seeds; (4) more rapid production; (5) less seed required per unit area; (6) controlled seeding rate; (7) controlled depth of sowing; and (8) ability to spread fertilizers and some other amendments at the same time.

The disadvantages are: (1) machinery is restricted to uniform, near-level sites; (2) cost and time are increased; and (3) where seed mixes are used types of seed cause problems with machinery (size, awns, etc.) and variable drilling depth is not possible.

Various types of drills are available and are adapted to site and seed type. Seeding depths recommended range from 10 to 150 mm in the literature. Depth must be regulated according to seed size and site (arid, cold, erodable).

Seeding rates for drill seeding range from 5 to 22 kg/ha, depending on species and seed size.

Advantages of broadcast seeding are: (1) access is not a problem; (2) fertilizer can be spread simultaneously; (3) greater speed than other methods; (4) lower costs; and (5) variety of methods (hand, aircraft) available.

Disadvantages of broadcast seeding are: (1) higher seeding rates; (2) uneven dispersal; (3) poor seed coverage; (4) low establishment rate; and (5) loss of seed to birds, rodents, and wind.

Hand broadcasters are most suitable for small areas. Fixed-wing aircraft are most efficient for large, gently sloping, or elongated areas (such as rights of way). Helicopters are best used for small

areas in rough terrain and have proved to be more efficient than ground crews. A disadvantage of aerial seeding is lack of good flying weather.

Aircraft should be flown low to avoid seed loss and should have power-driven seed metering devices. Several such devices have been tested and formulae are available for calculating seeding rates.

Seed distribution achieved from aircraft depends upon seed weight. Heavier seed tends to give better distribution; light seed should be mixed with a filler to achieve more even spread.

Individual species vary with respect to broadcast seeding rate. More research is required on rates; however, 56 kg/ha is a general rule of thumb and probably a maximum rate for most sites. Higher rates may be warranted when fertilizer application is low or for problematic seed-beds or sites.

Comparisons of drill versus broadcast seeding indicate that drill seeding is better than broadcast seeding for large seeded species; the reverse is true for small seeded species but more seed is required. Broadcast rates are generally twice drill rates in any case. Broadcast seeding is superior in terms of production, diversity, and stand composition. If seed is scarce, however, drill seeding is the more logical choice.

Hydroseeding advantages are: (1) it is useful for steep or wet areas; (2) even seed distribution is achieved; and (3) excess planting depth is avoided.

Disadvantages of hydroseeding include: (1) high cost; (2) problems with high winds; (3) damage to seed; (4) impaired germination from fertilizers in the slurry; and (5) seed tends to get "hung up" in mulches.

The hydroseeding slurry, made up of seed, water, fertilizer, and mulch in various combinations should not exceed a ratio of 224 kg solid per 455 L of water. This is a maximum and much lower ratios are better. The mix must be continuously agitated and seed should not be left too long in the tank. This is particularly critical for pelleted inoculated seed. Damage to seed or separation from inoculum varies with type of agitator, seed size, and time in the tank.

Methods of application vary. The thickness of the slurry layer and number of applications varies with site. Best results may often be achieved by applying seed and fertilizer first, followed by a mulch.

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32. ESTABLISHMENT OF GRASSES AND FORBS BY PLANTING

Transplanting mature grass plants is one of the most successful methods of binding sandy soils because mature plants are hardier than seedlings and can be planted deeper so as to take advantage of better moisture conditions. Also, transplants immediately form a vegetative cover, stabilizing the sand and reducing erosion (Thompson 1969). Walker, Sadasivaiah and Weijer (1977) found that container transplants of native grasses in the Rocky Mountains had extremely high survival rates in areas that were virtually barren. They noted that transplanting circumvents the seedling establishment phase where mortality is expected to be greatest.

Transplanting of grasses may be accomplished by sprigging (single shoots), or by use of containers or clumps of sod. Sodding has several major disadvantages: (1) it is expensive, (2) material may have limited availability, and (3) sod generally requires large amounts of water for establishment and maintenance (Sindelar 1973).

As part of a study to determine methods for reclaiming sand dunes near Lesser Slave Lake, Alberta, Lesko (1974) studied the performance of transplanted native sod clumps of Elymus innovatus. The transplants grew taller than all seeded species and produced significantly more biomass than all other species except E. junceus. Lesko concluded that although the transplants were highly successful, the high cost of transplanting would limit large scale use.

May et al. (1971) and Thompson (1969) studied establishment and survival of two grass species planted as sod or sprigs on alpine coal spoils in Wyoming. In general, spoils were acidic, with a high soluble salt content. The two species, both native to Alberta, were Agropyron smithii and Distichlis spicata var. stricta.

In the experiment, clumps of sod 10.2 cm^2 were planted deep enough to ensure the clumps were level with the surrounding surface. Sprigs were planted in rows as individual rhizomes, usually with a live blade or shoot, in slits 10.2 to 15.2 cm deep. Rows were approximately 30.5 cm apart. Plantings were made in June and August of 1967 and in

April 1968 to test the effect of planting time. All plantings were assessed for percent survival in August 1968.

As the percent survival varied according to age of spoil and topographic location (Table 32.1) only the following general conclusions may be drawn from this study:

1. Sodding gave far better results than did sprigging. The reason for this was that roots were damaged and too much moisture was lost from plants when being prepared for sprigging. The roots within the clumps of sod stayed moist and were protected by the surrounding soil. Sodding also required far less time than sprigging.
2. The best time of year to plant is during the spring and if possible during a rainy spell. Early fall planting proved mostly unsuccessful. May et al. (1971) felt that although late fall planting was not tried it should be nearly as successful as early spring planting.
3. Agropyron smithii seems to be the best adapted of the two species although Distichlis spread more vigourously on favorable sites and was better adapted to planting during dry periods. Schwendiman (1973) recommended moving material only when it is dormant to ensure best establishment results.
4. Thompson (1969) stated that although the techniques proved successful, it is doubtful if this method of revegetation could be economically feasible.

Leiser et al. (1974) tested the effect of two peat pot sizes (6 x 6 cm versus 5 x 5 cm) of Agropyron smithii cv. Barton, A. riparium cv. Sodar or Agropyron tricophorum cv. Topar on plant establishment in alpine areas of California. Early indications were that the larger containers were superior in terms of erosion control and survival.

Aldon, Knipe and Garcia (1973) transplanted three-month-old seedlings of A. smithii as 10.2 x 10.2 x 10.2 cm planting bands onto two alpine sites in New Mexico. Seedlings were planted at 61 cm intervals after summer rains had begun. After two growing seasons 84 percent of

Table 32.1. Percent survival by species, site, method, time and treatment of planting on alpine coal spoils in Wyoming, first week of August, 1968.

	TNF[a]	TSF[b]	ENF[c]	ESF[d]
Agropyron smithii Rhizomes				
3 yr site June, 67 planting	36%	42%	32%	66%
9 yr site June, 67 planting	4%	12%	0%	2%
2 yr site August, 67 planting	0%	0%	0%	0%
10 yr site August, 67 planting	0%	0%	0%	0%
2 yr site April, 68 planting	80%	90%	35%	100%
10 yr site April, 68 planting	45%	75%	10%	75%
Distichlis spicata Rhizomes				
3 yr site June, 67 planting	14%	40%	4%	8%
9 yr site June, 67 planting	15%	0%	0%	0%
2 yr site August, 67 planting	0%	0%	0%	0%
10 yr site August, 67 planting	0%	0%	0%	0%
2 yr site April, 68 planting	0%	5%	0%	0%
10 yr site April, 68 planting	0%	15%	0%	5%
Agropyron smithii Clumps				
3 yr site June, 67 planting	100%	95%	60%	95%
9 yr site June, 67 planting	85%	90%	5%	10%
2 yr site August, 67 planting	0%	0%	0%	0%
10 yr site August, 67 planting	0%	0%	0%	0%
2 yr site April, 68 planting	50%	90%	30%	85%
10 yr site April, 68 planting	80%	85%	35%	65%
Distichlis spicata Clumps				
3 yr site June, 67 planting	95%	95%	75%	45%
9 yr site June, 67 planting	25%	15%	0%	0%
2 yr site August, 67 planting	20%	50%	30%	40%
10 yr site August, 67 planting	35%	10%	0%	0%
2 yr site April, 68 planting	25%	55%	30%	30%
10 yr site April, 68 planting	90%	45%	15%	5%

Source: Thompson (1969).

[a] TNF - Top no snowfence

[b] TSF - Top snowfence

[c] ENF - East slope no snowfence

[d] ESF - East slope snowfence

the plants were still alive and 64 percent had produced daughter plants from rhizomes.

Cable (1977) also transplanted A. smithii on alpine, unweathered coal mine spoils in New Mexico (elevation = 2100 m). Six-week-old seedlings were grown in containers 2.5 cm in diameter at the top and 11.4 cm deep. Leaves were trimmed to 7.5 cm at planting time. Plants were placed in rows 30.5 cm apart. Three tools were used for making the holes in which the plugs were inserted: (1) a planting bar, (2) a posthole digger, and (3) a round bar. Ninety percent of the plants were alive after the first growing season, even though precipitation was 50% below normal. Differences in vigour due to planting method were not significant.

The authors of both these studies concluded that A. smithii transplants would be useful in establishing plants on small problem areas where direct seeding would have little chance of success.

Brown and Johnston (1978) planted 5300 plugs of native and introduced grass species in an alpine mine site on Beartooth Plateau, Montana (elevation = 3000 m) using a spacing of 0.6 m. Overall mean survival after one growing season was 65% (Table 32.2); the average for native species was 75% while the introduced species fared poorly (39%). The authors noted that more research is required to determine the applicability of this method to reclamation work.

Transplants of native grasses, sedges, and forbs on Iron Mountain and Beartooth Plateau, Montana have been extremely successful (Brown et al. 1976). In some locations, seed produced by the transplants has produced an abundance of young seedlings on the lee side of the plants, and many of these have become well established. Transplants are usually capable of seed production after only one growing season. The authors believed the success was due to: (1) the plants being dormant when transplanted, thus reducing physiological damage; (2) the well developed root systems; and (3) root crown portions not being as susceptible to dessication and frost heaving as are young emerging seedlings.

Table 32.2. Summary of first-year results of transplant survival and production on the McLaren Mine, Montana.

Species	Percent Survival	Ave. dry wt. per plant gm[a]	No. Planted 1976
NATIVES			
Agropyron scribneri	100	2.0	8
A. trachycaulum	83	1.4	124
Deschampsia caespitosa	72	2.4	993
Phleum alpinum	73	3.5	1016
Poa alpina	80	3.7	1682
Trisetum spicatum	24	0.9	86
Total/Average	75	2.3	3909
INTRODUCED			
Alopecurus pratensis	72	0.9	349
Bromus inermis	29	1.3	272
Dactylis glomerata	7	1.1	270
Festuca arundinacea	24	0.5	245
Phleum pratense	40	1.1	248
Poa compressa	91	6.5	70
Total/Average	39	1.9	1454
Total/Average All Species	65	2.1	5363

Source: Adapted from Brown and Johnston (1978)
[a] 1 gm = .035 oz.

Jensen and Sindelar (1979) and Sindelar (1973) tested "dryland sodding" on a roadside area near Forsyth, Montana which had been subjected to serious erosion in the past. Dryland sodding is a technique developed for arid regions involving the use of native rhizomatous grasses without artificial application of water during or following sodding.

Three native sod-forming grasses were used in the study: (1) Agropyron smithii, (2) Distichlis stricta, and (3) Poa pratensis. P. pratensis and D. stricata were sodded in spring (1972) and fall (1971) as 3.8 or 7.6 cm thick blocks. A. smithii was only sodded in spring (1972) as 7.6 cm blocks as most of its rhizomes were concentrated below 5.1 cm. Dormant grass was cut to 2.5 cm in height, and sod was cut into blocks 45.7 cm wide, varying from 45.7 to 121.9 cm in length depending on species and thickness. P. pratensis formed a strong sod in both thicknesses and was easily handled. D. stricata was more difficult to handle in the 3.8 cm thickness as most of the rhizomes were concentrated below 2.5 cm, causing the sod to break up easily. Sod was hauled to the site, packed firmly by a wide-tired tractor, staked in place, and fertilized. Sodding success was evaluated in terms of erosion control, survival, and vigour of the species.

Shoot density of the 7.6 cm P. pratensis sod was slightly higher than the 3.8 cm sod (Table 32.3). D. stricata gradually disappeared from plots following sodding and was replaced by Agropyron cristatum growing from small, repressed plants in the sod. The researchers assumed that cutting the grass inhibited Distichlis growth, allowing the Agropyron to proliferate. Spring sodding produced a greater Agropyron density in the 7.6 cm sod and a greater Distichlis density in the 3.8 cm sod. Differences in density of plants sodded in fall were minimal.

The Distichlis stricata-Agropyron cristatum mixture produced significantly more root material in the top 15 cm of soil when planted as 7.6 cm sod (Table 32.4). There was no difference in root production of P. pratensis between sod thicknesses; however, fall sodded plants produced a greater root weight than spring sodded plants.

Table 32.3. Shoot density of three sodgrasses and one bunchgrass (shoots/m^2). Grass planted in fall 1971 or spring 1972 and sampled June 1972 and 1973, near Forsyth, Montana.

	3.8 cm				7.6 cm			
	Fall		Spring		Fall		Spring	
	1972	1973	1972	1973	1972	1973	1972	1973
Kentucky bluegrass	4527.3	1623.2	2119.4	1264.8	5240.0	1920.3	2872.9	1509.1
Inland saltgrass	183.0	139.9	334.8	151.8	164.7	79.7	109.8	94.7
Crested wheatgrass	3449.9	2261.5	2329.3	2137.7	3206.6	2242.1	3405.7	2314.3
Western wheatgrass	ND[a]	ND	ND	ND	ND	ND	1218.5	442.4

Source: Adapted from Jensen and Sindelar (1979).
[a] ND = No data

Table 32.4. Root production of sodded species at Colstrip Interchange, Montana, (gm/m^3).

	3.8 cm		7.6 cm	
	Fall	Spring	Fall	Spring
Kentucky bluegrass	117	79	113	86
Inland saltgrass-crested wheatgrass	93	90	114	117
Western wheatgrass	ND[a]	ND	ND	66

Source: Adapted from Sindelar (1973).
[a] ND = No data

From these first year results Sindelar and Jensen recommended fall sodding of 7.6 cm P. pratensis as the best method of erosion control. Agropyron smithii produced an effective erosion control cover but was difficult to handle. Distichlis stricata performed poorly, and Sindelar (1973) felt that A. cristatum would not be suitable for dryland sodding as it is a bunchgrass. Costs were not excessive when compared to concrete or asphalt erosion control devices used elsewhere in the region.

Chosa and Shetron (1976) transplanted twenty-five isolated clumps of Phalaris arundinacea onto a slope leading to an iron mill waste pond in Michigan. Although they obtained 100% survival they have eliminated this method from further reclamation work due to the cost and amount of time required to collect and plant the grass.

32.1 SUMMARY

Planting provides an immediate stabilizing cover to a disturbed site and survival rates are generally high. Sprigging, sodding, and container planting are methods available.

Sprigging is time consuming and appears to be the least successful method due to root damage and moisture loss; therefore, it is not often used.

Sodding provides better cover than the other two methods. It is more successful and less time consuming than sprigging. However, sodding requires large amounts of water, material is often of limited availability, and it is expensive. Success of sodding varies with species and depends largely on root distribution and the length to which grass is cut. Species vary in ease of handling.

Container planting provides very successful stands and handling of stock is easier than for the other two methods. Transplants are less susceptible to environmental factors than sprigs or seedlings and are capable of producing seed after one growing season. The larger the container the greater the success; however, cost benefit must be carefully considered.

All planting methods are more time consuming and costly than seeding and are generally practical for very specific problem situations requiring immediate establishment and fast reproduction.

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33. TOPSOILING AND SIMILAR AMENDMENTS FOR ESTABLISHMENT OF GRASSES AND FORBS

The practice of stripping and stockpiling topsoil or other suitable surface material during initial mining for subsequent covering of waste materials is being widely recommended as a method of improving the success of revegetation programs (Hathorn, Docksteader and McQueen 1979).

The spreading of natural surface soil on spoils has a number of beneficial effects upon revegetation of mined land. It provides a fertility not usually encountered in raw spoils, furnishes a source for renewed microbiological activity to improve soil-building processes, and has better infiltration and soil stability characteristics (Packer and Aldon 1978). Dean et al. (1973) noted that dark topsoil applied to light coloured copper tailings in Arizona provided some protection from heat reflection and offered a more favorable environment for germination and seedling establishment.

Topsoil may also act as a seed source for the revegetation of spoils (Howard and Samuel 1979; Beauchamp, Lang and May 1975; Lesko 1974). Hassell (1977) and Usui and Suzuki (1973) discussed the use of soil "plates" to revegetate disturbed sites. Stockpiled topsoil containing an accumulation of ready-prepared and aged native adapted seed may be spread out to a depth of 5.1 to 10.2 cm and left to allow natural germination and establishment of plants (Hassell 1977). In Japan, Usui and Suzuki (1973) used a pressed plate of soil with fertilizer on which seeds were sown. The plates act as an artificial A horizon on eroded soil; however, their fertility did not appear to be enough to sustain growth for long periods.

The addition of topsoil to a spoil surface is not an absolute requirement to successful reclamation; however, topsoiling probably significantly reduces the time period required for reclamation (Schumacher, Hermesh and Bedwany 1977).

33.1 NORTH-EAST (OIL SANDS) REGION

In early work on the tailings dike at Suncor, near Fort McMurray, Alberta, Berry and Klym (1974) and Berry (1970) studied the effects of topsoiling with muskeg or muskeg and clay on the establishment of a grass/legume mixture. The amendments and fertilization regime are shown in Table 33.1. Following seed-bed preparation the plots were fertilized and harrowed. A seed mix consisting of 33% Bromus sp., 24% Agropyron cristatum, 15% Festuca rubra, 14% Trifolium repens, and 14% T. hybridum by weight was broadcast at a rate of 33.6 kg/ha on 06 June and harrowed in. Data on percent germination and height of plants were taken one month later to assess plant establishment.

Percent germination and plant height were greater in plots with sand and muskeg only (Table 33.2). Berry and Klym suggested that while more plant nutrients were retained in plots amended with clay, nutrient retention in plots with muskeg only could be improved by reducing the quantity of fertilizer per application and increasing the number of applications. They concluded that the extra expense of hauling suitable clay to mix with tailings sand did not warrant the advantage gained in retaining more plant nutrients; therefore, a mixture of muskeg and sand in a 1:1 ratio was recommended for future seed-beds.

Takyi et al. (1977) studied the effects of soil amendments and fertilization (N, P, K, S, and lime) on two grass/legumes mixes sown in pots in the greenhouse.

The soil mixes were:

1. tailings sand (1600 g per pot);
2. tailings sand (840 g)-GCOS peat (160 g) mixed in an approximate ratio of 1:1 by volume, per pot;
3. tailings sand (850 g)-GCOS overburden (750 g) mixed in an approximate ratio of 1:1 by volume, per pot;
4. tailings sand (1050 g)-GCOS peat (80 g)-GCOS overburden (470 g) mixed in an approximate ratio of 2:1:1 by volume, per pot; and
5. agricultural soil (Malmo; 1200 g per pot).

Table 33.1. Seed-bed preparation and fertilization rates at Suncor, Fort McMurray, Alberta, 09 July, 1970.

Plot No.	Seed-bed Mixture	Ratio of Mixture	Rate of Fertilization
1	Sand only		897 kg/ha
2	Sand & muskeg	7.6 cm muskeg spread over top of sand	897 kg/ha hand-raked into muskeg
3	Sand & muskeg	10.2 cm sand and 10.2 cm peat	673 kg/ha harrowed in 224 kg/ha hand-raked with seed
4	Sand & muskeg	10.2 cm sand and 10.2 cm peat	448 kg/ha harrowed in 224 kg/ha hand-raked with seed
5	Sand, muskeg and black clay	10.2 cm sand, 20.3 cm muskeg, and 10.16 cm black clay	673 kg/ha harrowed in 224 kg/ha hand-raked with seed
6	Sand, muskeg and black clay	10.2 cm sand, 20.3 cm muskeg and 10.2 cm black clay	448 kg/ha harrowed in 224 kg/ha hand-raked with seed
7	Sand, muskeg and black clay	10.2 cm sand, 10.2 cm muskeg and 10.2 cm black clay	673 kg/ha harrowed in 224 kg/ha hand-raked with seed
8	Sand, muskeg and black clay	10.2 cm sand, 10.2 cm muskeg and 10.2 cm black clay	897 kg/ha harrowed in 224 kg/ha hand-raked with seed

Source: Adapted from Berry (1970:3)

Table 33.2. Germination, growth and soil moisture on plots at Suncor, Fort McMurray, Alberta, 14 July 1970.

Plot No.	Germination Count (plants) Type	No.	Plant growth	Soil moisture	Remarks
1[a]	Clover grass	6 to 8 60 to 70	Clover, just sprouting grass, 5.1 to 10.2 cm high roots numerous 6.4 cm long.	Moisture in grooves at 7.6 to 10.2 cm top dry. Requires double quantity of water other than other plots.	Sand drifting and burying seedlings. 75% of plants show tip burning of leaves. Fertilized at 897 kg/ha.
2	Clover grass	60 to 80 130 to 150	Clover to 2.5 cm, grass 5.1 to 12.7 cm. Roots of grass numerous 7.6 to 10.2 cm long, penetrating beneath muskeg.	Ample moisture to support plant growth. Sand moist beneath muskeg.	Very little tip burning of plant leaves. Growth is thick especially clover. Rate of sowing at 34 kg/ha too great. Fert. at 897 kg/ha.
3	Clover grass	50 to 60 130 to 140	Clover to 5.1 cm high. Grass 5.1 to 12.7 cm high. Roots of grass 7.6 to 12.7 cm long.	Top of ground dry. Moisture at 7.6 cm.	Very little tip burning of plants. No soil drifting or erosion. Fertilized at 897 kg/ha.
4	Clover grass	20 to 30 90 to 100	Clover to 2.5 cm high. Grass 5.1 to 10.2 cm high. Roots of grass 7.6 to 12.7 cm long.	Top of ground dry. Moisture at 7.6 cm.	Very little tip burning of plants. No soil drifting. Some erosion. Fertilized 673 kg/ha.
5	Clover grass	15 to 20 65 to 70	Clover to 2.5 cm high. Grass 5.1 to 10.2 cm high. Roots of grass 5.1 to 10.2 cm long.	Top of ground dry. Moisture at 7.6 cm.	Very little tip burning of leaves. Growth in grooves cut by harrows and intracks made by Nodwell good. Between harrow grooves, growth is thin. Fertilized at 897 kg/ha.

Continued

Table 33.2. Concluded.

Plot No.	Germination Count Type	Germination (plants) No.	Plant growth	Soil moisture	Remarks
6	Clover grass	25 to 30 65 to 70	Clover at first leaves. Grass to 5.1 to 10.2 cm high. Roots of grass 5.1 to 10.2 cm long.	Top of ground dry. Moisture at 7.6 cm.	Tip burning of leaves of plants. Clover is stunted. There is a barren strip in centre for full length of plot, evidence of lean tar sands. Fertilized at 673 kg/ha.
7	Clover grass	30 to 40 60 to 70	Clover at first leaves. Grass 5.1 to 10.2 cm high. Roots of grass 5.1 to 10.2 cm long.	Top of ground dry. Moisture at 7.6 cm.	Tip burning of leaves of plants. Medium stand of plants, growth more uniform than plot 6, fertilized at 897 kg/ha.
8	Clover grass	20 to 25 60 to 70	Clover at first leaves. Grass 5.1 to 10.2 cm high. Roots of grass 5.1 to 10.2 cm long.	Top of ground dry. Moisture at 7.6 cm.	Sand drifting on east side of plot and soil eroding. Some barren patches that have evidence of lean tar sands.

Source: Adapted from Berry (1970:6)

[a] For plot treatment description, see Table 33.1.

The grass-legume mixtures were:

1. Bromus inermis - Medicago sativa; and
2. Agropyron trachycaulum - Onobrychis sp.

Two crops were grown in this experiment: (1) 24 January to 16 May, and (2) 29 May to 27 September. Pots were sown with equal numbers of grass and legume seeds and thinned after one month to three plants of each species. Yields of legume tops, grass tops, and combined roots were calculated at the end of each cropping.

In both crops, total yield of the combined fertilization treatments was highest in the agricultural soil, followed by the tailings sand-peat-overburden soil mixture (Table 33.3). There were important fertilizer-treatment interactions however. Fertilization, without the addition of lime, depressed plant top yields in the amended tailings sand pots (except NPKS in the peat and overburden pot) in the first crop and depressed top yields in the tailings sand-peat mix in the second crop. The addition of amendments to the tailings sand, especially peat and overburden together, increased the yield of legumes (Table 33.4).

Takyi et al. (1977) concluded that plants could be grown on unamended tailings sand with high fertilizer applications but that additions of peat and/or overburden would increase yields substantially. The inclusion of both amendments appears to favour growth of legumes.

Takyi et al. (1977) initiated a greenhouse study to determine the effects of soil amendments on establishment, production, and rooting of Festuca rubra and Medicago sativa. The two species were sown in pots on the following two seed-beds: (1) tailings sand and peat (1:1 ratio by volume), and (2) peat in a 3.8 cm layer over tailings sand. The pots were fertilized and plants were harvested after four months.

Dry matter yields were considerably higher in the tailings sand-peat mix than in the pots with a layer of peat (Table 33.5). Roots in the mixed media were evenly distributed throughout the pot while roots were concentrated in the peat layer in the other pots. It was found that the latter set of plants could not hold the underlying tailings sand together.

Table 33.3. Dry matter yields (g/pot)[a] legume-grass mixtures grown in different soil amendments. First and second seedings.

Medium	First Seeding			Second Seeding		
	Tops	Roots	Total	Tops	Roots	Total
Tailings Sand[b]	1.34	1.20	2.53	2.43	2.31	4.74
Tailings Sand-Peat (1:1)	1.62	1.25	2.89	1.92	2.94	4.86
Tailings Sand-Overburden (1:1)	1.46	1.15	2.61	3.33	3.21	6.54
Tailings Sand-Peat-Overburden (2:1:1)	1.82	1.31	3.13	3.10	3.66	6.76
Agricultural Soil (Malmo)[c]	3.77	1.78	5.57	4.48	4.81	9.29

Source: Adapted from Takyi et al. (1977).

[a] Yields are means of two replicates and four fertilizer-lime treatments.

[b] Sand, peat and overburden from the Syncrude Canda lease, Fort McMurray, Alberta.

[c] A high percentage of the fine roots in the Malmo could not be recovered.

Table 33.4. Percent composition of grasses and legumes grown on different soil mixes in a greenhouse (dry yields of tops).

	Grasses (%)			Legumes (%)		
	First Seeding	Second Seeding	Mean	First Seeding	Second Seeding	Mean
Tailings Sand[a]	86.6	76.0	81.3	13.4	24.0	18.7
Tailing Sand:Peat (1:1)	84.3	73.5	78.9	15.7	26.5	21.1
Tailings Sand:Overburden (1:1)	73.7	67.5	70.6	26.3	32.5	29.4
Tailings Sand:Peat:Overburden (2:1:1)	74.1	59.4	66.8	25.9	40.6	33.2
Agricultural Soil (Malmo)	67.0	54.7	60.9	33.0	45.3	39.1

Source: Takyi et al. (1977).
[a] Sand, peat and overburden from the Syncrude Canada lease, Fort McMurray, Alberta.

Table 33.5. Dry matter yields of creeping red fescue-alfalfa mixture on two types of tailings sand-peat mixes in greenhouse pots.

Treatment	Yield (g/pot)				Percentage distribution of Roots	
	Tops	Roots		Total		
		Top 4 cm	Bottom 4 cm		Top 4 cm	Bottom 4 cm
Peat placed on surface of sand[a]	3.39	3.44	0.66	7.49	83.9	16.1
Peat mixed in with the sand (1:1 v/v)	4.73	3.19	4.18	12.10	43.3	56.7

Source: Adapted from Takyi et al. (1977).
[a] Tailings sand and peat from the Syncrude Canada lease, Fort McMurray, Alberta.

Takyi et al. (1977) concluded that deep incorporation of peat would improve the erosion controlling capabilities of the vegetative cover.

Following the above study, Rowell (1977a, 1978, 1979) compared the effects of four surface treatments on the rooting depths attained by the same grass/legume mix on the Suncor tailings dike.

The four surface treatments were:

1. Overburden added at 750 t/ha and tilled into the peat-tailings sand surface to a depth of 30 cm.
2. Extra peat added to give a depth of about 20 cm on the surface and the peat incorporated to a depth of 30 cm.
3. Overburden added at 1500 t/ha and tilled into the peat-tailings surface to a depth of 30 cm.
4. Peat (10 to 15 cm) tilled into the tailings sand surface to a depth of 15 cm.

Treatments 1 to 3 were limed and fertilized. Treatment 4 was fertilized at a lower rate. Plots were seeded in June and data on shoot biomass and root biomass at various depths were taken for the years 1976 to 1978.

In 1976, there were no differences in percent germination, plant height, top biomass, and root distribution between the four surface treatments. The greatest percentage of root mass occurred in the 0 to 15 cm depth. In 1977, there were no differences in total above ground or below ground yield between treatments; however, overall yields were up to 100% higher than the previous year. Yields from the 0 to 15 cm depth were significantly greater in Treatments 1 and 2. Distribution of roots below 15 cm were somewhat greater where amendments had been tilled to 30 cm. In 1978, there was a significantly lower plant top biomass from Treatment 4 (Table 33.6) than from other treatments. Total root yield was not different between treatments; however, the depth of rooting was improved by the deeper incorporation of the soil amendments.

Rowell noted that while deeper tillage increased the rooting depth of seeded plants there were no erosion problems in shallow tilled

Table 33.6. Dry matter yield of plants grown in four surface amendments, Suncor, Fort McMurray.

Treatment	Yield (kg/m^2)					Percentage distribution of roots		
	Tops	Roots						
		0 to 15 cm	15 to 30 cm	30 to 60 cm	Total	0 to 15 cm	15 to 30 cm	30 to 60 cm.
1	0.316	0.542	0.103	0.040	0.684	79	16	5
2	0.332	0.550	0.117	0.039	0.706	78	17	5
3	0.324	0.549	0.145	0.023	0.717	77	20	3
4	0.205	0.510	0.067	0.015	0.591	86	11	3
Significance	***				N.S.			
L.S.D.	0.065							

Source: Adapted from Rowell (1979)

Note: Results are means of three replicates.

soils and thus the practice of deeper tillage cannot be justified in terms of surface stability.

Rowell (1977a,b, 1978, 1979) studied the effects of several surface amendments on the establishment and growth of a grass/legume mix on the Suncor tailings dike.

Seventy-two plots were set up with three main treatments (fertilizers) and five subtreatments (amendments). The amendments were:

1. Peat tilled to a depth of 15 cm.
2. Overburden added at a rate of 750 t/ha (about 5 cm) onto the surface of applied peat.
3. Overburden added at a rate of 1500 t/ha (about 10 cm) tilled into the surface 15 cm of peat and tailings sand.
4. Overburden added at a rate of 750 t/ha tilled into the surface 15 cm of peat and tailings sand.
5. Peat tilled into a depth of 15 cm (i.e., as Treatment 1) but not seeded until October 1976.

Surface materials were spread as evenly as possible over the surface and tilled to a depth of 15 cm.

On 16 July, the grass/legume seed mix (Table 33.7) and a nurse crop of Avena sativa cv. Pendek were broadcast at 50 kg/ha, and 40 kg/ha respectively. After broadcasting, seed was gently raked into the surface and packed down with a 50 kg roller. Data on percent ground cover and dry matter yield for 1976 to 1978 are presented in Rowell (1977a, 1978, 1979) and the reader is encouraged to read the reports for more details.

No significant differences in yield or percent cover were found between surface treatments within fertilizer regimes A and C (Table 33.8). With fertilizer B, however, there were some unexplained differences in yield in the second and third seasons. Rowell concluded that fertilizer level was the most important factor controlling vegetation establishment and growth in this study.

Table 33.7. Seed mix and seeding rates used in surface amendment study, Suncor tailings dike, Fort McMurray, Alberta.

Species	Seeding Rate (kg/ha)
Altai Wild Rye	1.75
Streambank Wheatgrass	7.50
Smooth Brome	8.00
Hard Fescue	1.50
Pubescent Wheatgrass	7.00
Slender Wheatgrass	6.00
Red Top	0.25
Canada Blue Grass	0.50
Kentucky Blue Grass	0.75
Lupine	4.00
Cicer Milk Vetch	3.00
Sainfoin	5.00
Alfalfa Rhizoma	3.00
Pendek Oats	40.00

Source: Adapted from Rowell (1978).

Table 33.8. Dry weight yields of plants grown on five surface amendments, Suncor, Fort McMurray.

Treatment [a]	Yield (kg/m²)			
	Sept. 1976	June 1977	Sept. 1977	Sept. 1978
1A	0.293	0.107	0.268	0.143
2A	0.341	0.183	0.283	0.174
3A	0.393	0.096	0.265	0.167
4A	0.326	0.102	0.259	0.171
5A	--	--	0.204[b]	0.170
Significance	N.S.	N.S.	N.S.	N.S.
1B	0.300	0.157	0.303	0.351
2B	0.369	0.211	0.415	0.258
3B	0.318	0.227	0.336	0.232
4B	0.259	0.197	0.362	0.291
5B	--	--	0.264	0.278
Significance	N.S.	N.S.	LSD=0.065	LSD=0.071
1C	0.304	0.289	0.393	0.394
2C	0.343	0.277	0.435	0.321
3C	0.361	0.351	0.423	0.394
4C	0.246	0.366	0.426	0.393
5C	--	--	0.235	0.371
Significance	N.S.	N.S.	N.S	N.S.

Source: Adapted from Rowell (1977a, 1978, 1979).

[a] Three fertilizer levels: A = low; B = medium; C = high

[b] Tests of significance in Sept. 1977 do not include Treatment 5

33.2 MOUNTAINS AND FOOTHILLS REGION

Russell and Takyi (1979) set up four experiments to examine the effects of topsoil, fertilization, and companion crops on the establishment of native and agronomic grass and legume species on coal spoils near Cadomin, Alberta (elevation = 1675 m). The study site was about 32 ha in size and was characterized by extensive flat-topped spoil heaps composed largely of sandstone, siltstone, and shale overburden.

Plots were established on raw overburden or on overburden top-dressed with 20 cm of mineral soil stripped from a nearby, undisturbed subalpine forest. Plots were seeded in June and assessed for percent cover in early September. Takyi and Russell (1980) assessed percent cover, production, number of flowering tillers, and plant density in the second growing season. They did not provide statistical comparisons between topsoil and raw spoil treatments.

In the first experiment, trials were designed to test the adaptability of nine agronomic grasses and legumes and one agronomic grass-legume mixture. All seed was applied by hand at a rate of 60 kg/ha and plots were fertilized. Legume seed was dry mixed with the proper commercial inoculant just prior to sowing.

Cover was higher on top-dressed plots for three out of nine of the species and for the species mix in the first season. In the second growing season, eight out of nine of the species and the species mix had higher cover on the topsoiled plots. Melilotus sp. showed greater cover on the raw overburden both years. The number of flowering tillers on the grasses was consistently higher on topsoiled plots, especially for Poa pratensis cv. Park and Phleum pratense. Dry matter production, with the exception of Melilotus, was at least twice as high on top-dressed plots as on the raw overburden. Plant height, with the exception of the Poa was somewhat greater on top-dressed plots (Table 33.9).

In the second experiment, trials were designed to test the effects of four seeding rates and five fertilizer rates on the performance of an agronomic seed mixture recommended for the area by the Alberta Forest Service. The agronomic seed mixture was composed of

Table 33.9. Second season cover, productivity, maximum plant heights and number of flower tillers for agronomic species growing on raw spoil and top-dressed spoil near Cadomin, Alberta.

Species	% Cover		Production		Maximum plant height		No. flowering tillers	
	Raw spoil	Spoil top-dressed with soil	Raw spoil (g/m^2)	Spoil top-dressed with soil	Raw spoil (cm)	Spoil top-dressed with soil	Raw spoil (tillers $/m^2$)	Spoil top-dressed with soil
1. Kentucky bluegass *(Poa pratensis)* 'Nugget'	18.5	30.0	1.2	4.8	15.5	25.0	12.0	60.8
2. Kentucky bluegrass *(Poa pratensis)* 'Park'	30.0	63.2	4.1	19.5	45.7	44.3	23.2	138.0
3. Bromegrass *(Bromus inermis)* 'Carlton'	31.7	41.5	7.9	20.8	58.7	74.7	11.2	56.0
4. Creeping red fescue *(Festuca rubra)* 'Durlawn'	16.2	45.7	4.8	10.5	25.5	35.7	0.0	4.0
5. Crested wheatgrass *(Agropyron desertorum)* 'Nordan'	27.2	36.0	8.6	18.3	56.5	58.3	16.8	28.8
6. Timothy *(Phleum pratense)* 'Climax'	45.7	69.2	9.0	26.2	60.3	69.7	12.0	104.0
7. Alsike clover *(Trifolium hybridum)* 'Aurora'	11.0	24.0	1.0	7.6	15.0	16.0		
8. Alfalfa *(Medicago sativa)* 'Rambler'	27.5	40.7	8.5	20.8	40.5	51.5		
9. Sweet clover *(Melilotus officinalis)* 'Yukon'	52.5	43.0	45.2	38.6	97.0	108.5		
10. Species mix (all above species)	50.2	69.0	19.1	38.4	129.0	127.3		

Source: Adapted from Takyi and Russell (1980).

Festuca rubra (40% by weight), Trifolium repens (12%), Phleum pratense (24%), and Poa compressa cv. Canon (24%). All legume seed was dry mixed with the proper commercial inoculant just prior to sowing.

In the first and second growing seasons plant cover was higher on the unfertilized topsoiled plots than on the unfertilized raw spoils (Table 33.10). The effect of fertilizer masked surface amendment effects for many of the seeding rate-fertilizer rate combinations. However, Takyi and Russell noted that greater cover on raw spoils may be due to: (1) higher plant establishment rates resulting from more favourable microsite conditions afforded by the coarse textured overburden; (2) lower establishment rates on mineral soil due to surface crusting; and/or (3) erosion of seed from the mineral soil plots by wind or downslope water movement.

In the second season, flowering tiller density was considerably higher for the top-dressed plots (Table 33.10). Dry matter production was generally greater on top-dressed plots as was species frequency.

In the third experiment, trials were designed to test the adaptability of 13 native and two agronomic grass species. All seed was applied by hand at a rate of 5000 seeds/m^2 and all plots were fertilized.

By the second season, cover on both media had improved over the previous season. Approximately one-third of the seeded species had greater cover on the top-dressed plots (Table 33.11). Flower tillering was greater on top-dressed plots for most species. In all but three species (Koeleria cristata, Stipa columbiana, Festuca idahoensis), maximum plant height was achieved on the topsoiled plots (Table 33.12). Seed production on top-dressed plots was as good as or better than that on the raw overburden.

In the fourth experiment, trials were designed to test the effects of two seeding rates, three fertilizer rates, and four nurse crops on the performance of a native grass seed mixture. The seed mix was composed of equal numbers of seeds of Agropyron trachycaulum (69% by weight), Festuca saximontana (15%), Poa interior (8%), and Trisetum

Table 33.10. Percent cover, number of flowering tillers, and dry matter production of an agronomic seed mix sown at four rates and fertilized at five rates, on coal spoils near Cadomin, Alberta.

Treatment Rates		Cover %		Flowering Tillers #/m²		Production g/m²	
Fertilizer NPK kg/ha	Seeding kg/ha	Raw Spoil	Top-dressed	Raw Spoil	Top-dressed	Raw Spoil	Top-dressed
0-0-0	30	0.0	3.7	0.0	8.3	ND[b]	1.1
	60	0.3	20.7	2.0	26.7	ND[b]	1.6
	90	0.7	8.7	0.0	13.0	ND[b]	1.4
	120	3.0	5.0	0.0	6.3	ND[b]	1.5
40-20-40	30	47.0	31.3	1.0	136.3	3.1	6.1
	60	39.3	41.3	4.7	88.0	4.5	4.7
	90	60.0	46.7	1.3	102.0	2.8	7.6
	120	51.9	56.0	0.0	99.3	3.1	8.6
60-30-60	30	68.7	48.3	2.3	214.7	4.5	12.7
	60	60.7	62.0	2.0	251.3	4.9	12.2
	90	87.0	48.0	0.0	177.0	8.5	11.7
	120	70.7	61.7	6.3	107.0	10.8	9.9
80-40-80	30	69.7	60.3	29.0	237.7	11.3	17.8
	60	85.7	60.7	4.3	218.0	7.5	21.4
	90	82.3	61.7	6.0	213.7	8.7	18.5
	120	87.7	66.7	5.0	103.7	5.8	12.7
80-40-80[a]	30	58.7	71.0	29.0	396.0	8.9	15.7
	60	88.0	58.3	31.0	304.3	9.0	12.4
	90	81.3	51.7	18.7	306.3	5.7	16.0
	120	77.9	67.0	29.3	215.7	11.4	20.5

Source: Adapted from Russell and Takyi (1979) and Takyi and Russell (1980).

[a] Split application - half 21 June, half 3 August.

[b] Production was too poor to allow cropping.

Table 33.11. Second season percent cover and flowering tiller production of native and introduced grass species established on raw overburden and overburden top-dressed with mineral soil, near Cadomin, Alberta.

Species	Percent Cover		Tiller Production[c]	
	Raw Spoil	Topsoil	Raw Spoil	Topsoil
Agropyron dasystachyum	27.6[b]	26.1	3.8	4.0
Agropyron subsecundum	11.9	20.9	1.8	4.0
Agropyron trachycaulum	27.3	20.5	3.0	4.0
A. trachycaulum 'Revenue'[a]	15.9	15.0	4.0	4.0
Calamagrostis purpurascens	1.5	4.1	0.5	1.8
Deschampsia caespitosa	3.9	10.0	0.3	1.0
Festuca idahoensis	4.1	2.6	0.0	0.0
Festuca rubra 'Boreal'[a]	14.0	21.2	0.8	3.0
Festuca saximontana	9.3	4.1	1.3	2.3
Festuca rubra	7.9	14.5	0.0	0.8
Koeleria cristata	6.0	4.1	0.3	1.0
Phleum alpinum	5.0	8.1	0.8	1.5
Poa interior	0.8	3.0	4.0	4.0
Stipa columbiana	2.4	0.6	0.0	0.3
Trisetum spicatum	2.3	7.2	1.0	3.5

Source: Adapted from Russell and Takyi (1979) and Takyi and Russell (1980).

[a] Introduced cultivars (check species).

[b] Mean value based on a sample size of 4.

[c] Flowering tiller production ratings: 0 = no flowering tillers; 1 = 1 to 25% of plants with flowering tillers; 2 = 26 to 50%; 3 = 51 to 75%; 4 = over 75%.

Table 33.12. Maximum plant height and seed production ratings of native and introduced grasses established on raw overburden and top-dressed overburden, near Cadomin, Alberta.

Species	Raw spoil		Topsoil	
	Plant Height (cm)	Seed Production[b]	Plant Height (cm)	Seed Production
Agropyron dasystachyum	28.5	3	33.0	4
Agropyron subsecundum	27.0	2	42.0	3
Agropyron trachycaulum	31.3	3	35.8	3
A. trachycaulum 'Revenue'[a]	42.2	4	49.3	4
Calamagrostis purpurascens	8.0	1	12.8	2
Festuca saximontana	8.3	2	12.5	2
Koeleria cristata	13.3	1	13.3	2
Phleum alpinum	14.0	1	27.0	2
Poa interior	6.0	3	7.0	3
Stipa columbiana	13.3	0	9.3	1
Trisetum spicatum	9.3	1	15.5	3
Deschampsia caespitosa	8.3	0	15.3	2
Festuca idahoensis	11.5	0	10.3	0
Festuca rubra	11.3	0	16.0	1
Festuca rubra 'Boreal'[a]	16.8	1	26.0	3

Source: Adapted from Takyi and Russell (1980).
[a] Introduced cultivars (check species).
[b] Ratings: 0 = no seed production; 1 = very poor to poor seed production; 2 = fair seed production; 3 = good seed production; 4 = excellent seed production.

spicatum (8%). The seeding rates, fertilizer rates, and cover crops are shown Table 33.13.

In the first season, cover was greater on the top-dressed plots than on the raw spoils; however, cover was very low for all treatments. The companion cover crop had no effect on cover. In the second season (Table 33.13), cover was approximately three times higher on top-dressed plots than on raw spoils, but cover was still low. Cover on unfertilized raw spoil was virtually nil while cover on unfertilized topsoil was approximately 3%. While there were significant differences between companion crops on top-dressed plots, none were significantly different than no companion crop.

From these studies Takyi and Russell noted that topsoiling generally improved plant production and tillering, especially in the absence of fertilizer applications. They also noted, however, that fertilization of raw spoils will produce acceptable stands of vegetation. More information is needed on how long the effects of topsoil will last as opposed to fertilized raw spoil.

Rutten (1972) established 10 plots on coal slack tailings near Lethbridge, Alberta to study the effects of applying 2.5 cm of either topsoil, manure, sewage sludge, or sawdust on the establishment of a grass/legume mix. The amendments were lightly raked into the coal and irrigation water was applied by a small solid set sprinkler system. Nine species or varieties were seeded in June in rows 30.5 cm apart (Table 33.14).

Growth on the untreated raw coal spoil was the slowest. All varieties except Medicago sativa and Melilotus sp. deteriorated severely after attaining a height of 2.5 cm. By the beginning of August only the Medicago and Melilotus were alive. In terms of plant growth, the topsoiled plot was intermediate between the raw spoil or sawdust amended plots (lowest) and the manure or sludge amended plots (highest). Root growth of legumes was only slightly better in the topsoiled plots than in the raw spoil. Rutten noted that with the exception of the sawdust amendment, the ameliorated plots had improved yield and growth rates over the unamended plots.

Table 33.13. Effects of seeding rate, fertilizer rate and companion crop treatment on percent plant cover of a native grass mix, sown on raw overburden and top-dressed overburden, Cadomin, Alberta.

Companion Crop	Fertilizer Rate, N-P-K (kg/ha)						Means (Companion Crop)
	0-0-0		40-20-40		80-40-80		
	Seeds/m^2		Seeds/m^2		Seeds/m^2		
	1000	5000	1000	5000	1000	5000	
Raw Spoil							
Barley	0.2	0.3	3.8	7.2	0.8	4.2	2.8 a
Red Clover	0.0	0.2	5.0	3.6	3.5	5.2	2.9 a
Grass-Legume Mix	0.0	0.5	8.5	7.0	5.8	5.2	4.5 a
None	0.0	0.3	8.5	5.0	0.8	2.8	3.0 a
Means: Fertilizer	0.2 a		6.1 c		3.5 b		
Topsoil							
Barley	1.8	3.8	13.7	11.3	11.8	14.8	9.6 ab
Red Clover	1.0	2.0	12.3	15.0	5.2	10.8	7.7 a
Grass-Legume Mix	5.0	3.5	25.8	29.3	13.5	18.5	15.9 b
None	4.3	2.7	11.7	22.5	5.3	10.5	9.5 ab
Means: Fertilizer	3.0 a		17.7 b		11.3 b		

Source: Adapted from Takyi and Russell (1980).
Note: Means followed by a common letter are not significantly different at the 5 percent level (Duncan's Multiple-Range Test).

Table 33.14. Grass and legumes seeded onto soil amendment plots near Lethbridge, Alberta.

Species/Variety	Seeding Rate (kg/ha)
Slender wheatgrass	13.4
Rambler alfalfa	11.2
Vernal alfalfa	11.2
Fairway crested wheatgrass	11.2
Tall fescue	11.2
Sweet clover	11.2
Creeping red fescue	9.0
Kentucky blue grass	6.7
Park Kentucky blue grass	6.7

Source: Adapted from Rutten (1972).

In contrast to the results of the above studies, Mihajlovich and Russell (1980) found a decrease in percent cover and standing crop on topsoiled plots compared to raw coal overburden plots. Plots were established at Tent Mountain, Alberta on raw overburden material and on overburden top-dressed with 7.5 to 10 cm of mineral soil stripped from a nearby undisturbed subalpine forest. All plots were hand raked to establish a uniform seed-bed, then broadcast seeded with 24 species at a rate of 1075 seeds/m^2 for each species (Table 33.15). All legume seed was mixed with the appropriate dry inoculant at the time of seeding. Plots were not fertilized, but were lightly mulched with peat moss after seeding.

The trials were assessed for cover after the first and second growing seasons and biomass measurements were made at the end of the second growing season. Seventeen of the 24 species tested attained equal or somewhat greater cover on the raw overburden than on top-dressed overburden. Mihajlovich and Russell noted that this may be the result of a rougher surface on the raw overburden which would provide more germination microsites (see also discussion of Takyi and Russell (1980) above). The differences in cover between the two growing media decreased by the second growing season. Seven of the ten legumes had greater biomass on the topsoiled plots while grasses had greater production on raw spoils (Table 33.15).

Hathorn, Docksteader and McQueen (1979) tested the effects of 5 cm of topsoil placed over eight potential coal mine waste materials on the biomass production of three grass/legume mixtures in Hat Creek Valley, British Columbia (elevation = 850 to 1220 m).

Seven potential waste materials from the proposed coal mine were selected as well as a large sample of fly ash from coal combustion tests. Materials were placed in plots 15 m square and 1 m deep and half of each plot was surfaced with 5 cm of topsoil. Plots were seeded in the fall with each of three seed mixes (Table 21.5). The fly ash plot was seeded with only two of the mixes. Data on density, height, and biomass were collected for each plot the following year.

Table 33.15. Percent ground cover and above-ground dry-matter production of 24 agronomic grass and legume species grown in identical field trials on raw overburden and top-dressed overburden materials at Tent Mountain, Alberta. Second season results shown.

Species	Seeding Rate (kg/ha)	Ground Cover (%)		Above-ground dry-matter production (kg/ha)	
		Raw Overburden	Top-dressed Overburden	Raw Overburden	Top-dressed Overburden
Creeping red fescue-Boreal	79	10[a]	10	636	478
Meadow fescue-Common Ensign	212	20	7	413	226
Chewings fescue-Common	79	17	9	323	217
Arctic fescue	79	16	0	559	322
Tall fescue-Alta	79	5	7	299	294
Pubescent wheatgrass-Greenleaf	488	15	7	867	560
Slender wheatgrass-Revenue	307	16	9	838	514
Crested wheatgrass-Parkway	279	12	6	357	300
Kentucky bluegrass-Merion	22	10	6	318	336
Canada bluegrass-Canon	20	12	2	456	703
Upland bluegrass	21	5	2	861	270
Smooth bromegrass	687	23	12	883	442
Timothy-Climax	40	11	11	734	495
Redtop-Common	10	5	4	339	253
Birdsfoot trefoil-Leo	122	1	2	13	189
Alfalfa-Rambler	79	1	1	40	82
Sweet clover-white blossom-Common	188	5	9	138	337
White clover-Common	61	0	4	5	56
Alsike clover-Aurora	70	2	11	92	281
Red clover	177	3	14	95	330
Sainfoin-Melrose	1626	2	1	13	10
Highland bentgrass	6	9	2	291	358
Russian wild rye-Sawki	279	9	4	251	140
Sweet clover-yellow blossom-Common	188	1	5	97	76

Source: Adapted from Mihajlovich and Russell (1980).
[a] Mean values are based on a sample size of three.

Table 33.16 presents data on plant emergence and biomass for topsoiled and non-topsoiled plots. Production was very poor on the carbonaceous shales and coal waste, and topsoil dramatically increased plant density and production. A smaller but nevertheless substantial increase also occurred with the gritstone and bentonitic clay materials, whereas there was a marked decrease on the colluvium and glacial gravels. The baked clay and fly ash showed variable responses to topsoiling. Invader species were much more common on the topsoiled plots.

The two principal conclusions from this study were:

1. "Revegetation of surficial materials such as colluvium, gravel and till was readily achieved. The sodic materials, gritstone and bentonitic clay proved more difficult to revegetate. The carbonaceous wastes would require a cover of suitable material in order to be revegetated in the first year. Fly ash, because of its fine and uniform texture would likewise benefit from a thin surface cover if vegetation for erosion control is to be established in the short term."
2. "The effect of topsoil was to increase emergence success and biomass on carbonaceous soils, gritstone and bentonitic clay, while on colluvium and gravel a decrease was observed. It is suggested that the retention of surficial materials such as colluvium and gravel with topsoil for the future surfacing of waste dumps would be beneficial." (Hathorn, Docksteader and McQueen 1979:241.)

Brown and Johnston (1976) compared establishment of grasses on acid, copper mine spoils and spoils amended with topsoil on the Beartooth Plateau in Montana. Seventy-two plots were established and half of them were covered with topsoil, consisting of the upper 60 cm of material from undisturbed native soil, spread to a depth of 20 cm. A mixture of native species and a mixture of introduced species were broadcast seeded with and without fertilizer in the fall at a rate of 56 kg/ha. The plots were then thoroughly raked and packed. Total plant

Table 33.16. Emergence and total biomass of plants sown on eight waste materials with and without topsoil, Hat Creek, British Columbia.

Growth Medium	Emergence (Plants/m²)[a]		Biomass (g/m²)[a]	
	No Topsoil	Topsoil	No Topsoil	Topsoil
Carbonaceous Shale	17	380	1.7	42
Coal Waste (reject)	147	333	5	39
Bentonitic Clay	270	363	24	65
Gritstone	293	380	31	72
Colluvium	520	403	272	246
Baked Clay	350	410	171	149
Glacial Gravels	393	317	130	110
Fly-Ash	340	320	73	124

Source: Adapted from Hathorn, Docksteader and McQueen (1979).
[a] Values are means for three seed mixtures

density was measured in September of the following year (Table 30.2). Topsoiled plots had greater densities than raw spoil plots under all treatments; however, cover (max = 2%) was low in all plots.

Farmer, Richardson and Brown (1976) studied the effects of topsoiling, fertilization, irrigation, and mulching on the establishment of native and introduced species on acid (pH 3.5 to 5.1) copper-cobalt mine spoils near Salmon, Idaho (elevation 2012 to 2499 m). Lime was applied at the rate of 896 kg/ha (CaO) two months prior to planting to increase spoil pH. Topsoil was applied to a depth of 20 cm and limed at a rate of 1792 kg/ha because of its greater cation exchange capacity. At planting time plots were harrowed to a depth of 15 cm, seed was broadcast and lightly raked in, and mulch and fertilizer were applied where appropriate. A Brillion Culti-Packer was used to pack the whole area. Mixtures of native, introduced, and native plus introduced species (Table 33.17) were seeded at 28.6 kg/ha in June.

Due to the complexity of the trials, only general conclusions are presented here and the reader is encouraged to read the report for more detailed results. The authors noted that of the three main plots, the fertilized, top-dressed plot had greater average plant densities and yield (Table 33.18) than the control or irrigated plots at the end of two growing seasons. They suggested that top-dressing with native topsoils and subsoils, combined with fertilization, appears to offer the best chance for the successful revegetation of waste piles at the Blackbird Mine.

Kenny and Cuany (1978) tested the effects of 7.6 cm of topsoil placed over graded subsoil on establishment of Bromus inermis on a ski slope at Steamboat Springs, Colorado (elevation = 2957 m). The plants on the topsoil had a higher percentage of establishment and persistence than those on subsoil. Plants on topsoiled plots were 7 to 15 cm taller than those on subsoil only plots. The authors attributed this success to an increased nutrient level and water holding capacity in topsoiled plots.

The effects of a 15, 30, or 60 cm soil cover on growth of a grass/forb/shrub seed mix sown on spent TOSCO and USBM oil shale at

Table 33.17. Seed mixtures and seeding rates used in surface amendment study, Salmon, Idaho.

Common Name	Scientific Name	Seeding rate (kg/ha)
NATIVE SPECIES		
Hairgrass	Deschampsia caespitosa	0.84
Bluebunch wheatgrass	Agropyron spicatum	3.40
Squirreltail	Sitanion hystrix	3.40
Basin wildrye	Elymus cinereus	9.24
Cheatgrass	Bromus tectorum	1.68
Western wheatgrass	Agropyron smithii	3.40
Balsamroot	Balsamorhiza sagittata	3.40
Western yarrow	Achillea millefolium	0.84
Goldenrod	Solidago sp.	2.52
		28.56
INTRODUCED SPECIES		
Crested wheatgrass	Agropyron cristatum	3.40
Intermediate wheatgrass	Agropyron intermedium	5.04
Orchardgrass	Dactylis glomerata	3.40
Kentucky bluegrass	Poa pratensis	1.68
Timothy	Phleum pratense	5.04
Smooth brome	Bromus inermis	5.04
Meadow foxtail	Alopecurus pratensis	1.68
Alta fescue	Festuca arundinacea	1.68
Yellow sweetclover	Melilotus officinalis	1.68
		28.56
NATIVE + INTRODUCED SPECIES		
Hairgrass	Deschampsia caespitosa	1.68
Timothy	Phleum pratense	3.40
Basin wildrye	Elymus cinereus	3.40
Orchardgrass	Dactylis glomerata	3.40
Intermediate wheatgrass	Agropyron intermedium	5.40
Western wheatgrass	Agropyron smithii	5.40
Smooth brome	Bromus inermis	3.40
Bluebunch wheatgrass	Agropyron spicatum	1.68
Crested wheatgrass	Agropyron cristatum	1.68
		28.56

Source: Adapted from Farmer, Richardson and Brown (1976).

Table 33.18. Average ground cover density (%) and yield (kg/ha) for three series of four treatments, by main plots, Salmon, Idaho.

Treatment Code[a]	Control Plot		Topdressed Plot		Irrigated Plot	
	Cover	Yield	Cover	Yield	Cover	Yield
N-F-M	18	303	39	992	25	549
N-F-NM	13	122	29	670	15	208
N-NF-M	12	100	11	73	11	81
N-NF-NM	11	79	8	53	13	124
P-F-M	25	519	83	2471	44	1161
P-F-NM	14	157	72	2082	18	315
P-NF-M	12	107	11	86	13	132
P-NF-NM	11	88	12	120	12	115
NP-F-M	20	373	76	2215	44	1164
NP-F-NM	14	164	78	2453	16	235
NP-NF-M	12	107	13	128	13	124
NP-NF-NM	11	88	12	236	12	236

Source: Adapted from Farmer, Richardson and Brown (1976).

[a] N = native; P = introduced; NP = native + introduced
F = fertilized; NF = not fertilized; M = mulch; NM - not mulched.

Anvil Points, Colorado (elevation = 1737 m) was studied by Harbert and Berg (1974). The TOSCO spent shale was a uniformly fine-textured (silt loam) black material. The USBM material was gray to black and contained about 60% coarse particles (> 2 mm diameter) and 40 percent soil-size particles which were a loam in texture.

Seven "soil-spent shale" treatments were tested on north and south exposures on a 25% slope. Plots were constructed by excavating 0.6 m of soil in an area 14.6 m wide and 20.1 m long and then filling the centre of the excavation with spent shale to a depth of between 1.8 and 2.4 m depending upon the depth of soil cover. The sites were then sloped to 25% and the excavated soil was used for the soil cover treatments. Construction of the plots was completed in April 1973.

Following construction, each plot was fertilized with P and leached with a total of 101.6 cm of water. The plots were seeded on 11 June with a mixture of native grasses and shrubs (Table 33.19). The plots were then raked lightly, mulched with hay held in place with cotton netting, irrigated and fertilized with N.

Data on percent cover were taken in September of the first and second growing seasons. Topsoiling improved cover on both spent shales in the first growing season over both the shale alone and the topsoil control. Increasing topsoil depth did not improve cover. By the end of the second season, cover had decreased on the TOSCO plots but the topsoiled plots still had more cover than the raw shales. On the USBM plots there was a much smaller decrease in plant cover (Table 33.20). Harbert and Berg attributed the decreased cover on the TOSCO plots to an increase in salinity on those plots.

Observations were made in 1974 on the time of plant growth initiation for each treatment. Growth began on the following treatments during the last week in April: (1) TOSCO spent shale with 30 cm of soil cover, (2) USBM spent shale with 15 and 6 cm of soil cover, (3) USBM raw spent shale, and (4) the soil control plots. Growth on the TOSCO spent shale with 15 cm of soil cover was initiated by the second week in May,

Table 33.19. List of species seeded and rate of seeding on the oil shale research plots at the Anvil Points, Colorado, study site.

Common Name	Scientific Name	Rate (kg/ha)
Grasses		
Bluebunch wheatgrass	Agropyron spicatum	2.2
Indian ricegrass	Oryzopsis hymenoides	2.2
Western wheatgrass	Agropyron smithii	1.1
Shrubs		
Big sagebrush	Artemisia tridentata	0.56
Fourwing saltbush	Atriplex canescens	1.1
Rabbitbrush	Chrysothamnus spp.	0.56
Winterfat	Eurotia lanata	1.1

Source: Adapted from Harbert and Berg (1974).

Table 33.20. Percent ground cover for the north and south aspects soil control, TOSCO and USBM spent shale and soil cover over TOSCO and USBM spent shale, Anvil Points, Colorado, study site.

Treatments	% Ground Cover			
	September 1973		September 1974	
	North	South	North	South
Soil Control	65	60	65	60
TOSCO spent shale	53	48	43	43
15 cm soil cover/TOSCO spent shale	80	80	63	58
31 cm soil cover/unleached TOSCO spent shale	80	80	63	60
USBM spent shale	55	57	55	55
15 cm soil cover/USBM spent shale	73	68	75	62
61 cm soil cover/unleached USBM spent shale	73	68	68	60

Source: Adapted from Harbert and Berg (1974).

but plant growth on the TOSCO raw spent shale did not begin until the last week in May.

Harbert and Berg pointed out that while growth on plots with a 30 cm soil cover was no better than on those with a 15 cm layer, the topsoil in the latter became resalinized while the 30 cm layer of topsoil was not salinized. This may have implications for the long-term survival of plants on the shallower topsoiled plots.

33.3 PLAINS REGION

McAllister Environmental Services Ltd. (1977a,b) set up several experiments near Round Hill, Alberta. The first study examined the yield of Hordeum cv. Bonanza and Agropyron cristatum sown on five combinations of potential coal overburden materials (Table 33.21). One half of each plot was covered with 15 cm of Ah material. Plots were constructed in June 1975 and summer fallowed for the balance of that year. Trenches were cultivated and seeded in May 1976. Fertilizer was applied 2.5 to 5 cm below the seed rows. Threshed grain yields from the Hordeum were calculated at the end of the first growing season.

Surfacing with Ah material increased yields significantly in all plots but one (Table 33.21). The discrepancy in Trench 4 was attributed to sampling error. Yields in Trenches 1 and 2 with an Ah layer and Trench 4 without an Ah layer were similar to yields on undisturbed land. An increasing proportion of shale adversely affected Hordeum yields (Trenches 1 versus 5), particularly in the absence of an Ah layer.

A second set of experiments studied the effects of various depths of rooting media with or without a 15 cm cap of topsoil. Two coal exploration pits were excavated. During the mining operations the Ah material, B and C horizons, and underlying till were separately stripped and stockpiled.

In Pit #3 (227 m long and 30.5 m wide), the two overburden materials were replaced with and without topsoil to provide four plots (Table 33.22). In Pit #2 (213 m long and 27 m wide), the mine spoil was replaced and three plots set up:

Table 33.21. Barley yields from mine spoils with and without topsoil, Round Hill, Alberta.

Trench	Growth Media	Barley Yields (hL/ha)[a,b]	
		With Topsoil	Without Topsoil
1	75% till - 25% shale	78.3[c]	56.3
2	Mine run spoil	67.8	50.7
3	100% till	80.5	52.4
4	Upper 4ft. of soil	64.7	73.5
5	50% till - 50% shale	66.2	28.6

Source: Adapted from McAllister Environmental Services Ltd. (1977a). Used by permission of TransAlta Utilities Corporation.

[a] Mean of 10 samples per plot.

[b] Yield differences in excess of 8.9 hL/ha are significantly different at the 5% level.

[c] Average yield on undisturbed land is 77.8 hL/ha.

Table 33.22. Bonanza barley yields on overburden materials, with or without a 15 cm Ah layer, Round Hill, Alberta.

Material	Yield (kg/ha)	with Ah	Without Ah
B & C horizons	4349	4270	4420
Till	3990	3960	4030
Difference	358	not significantly	
L.S.D. at 5%	301	different	

Source: McAllister Environmental Services Ltd. (1977b). Used by permission of TransAlta Utilities Corporation.

1. subsoil was placed as a wedge of growth media increasing from 0 cm to 60 cm over mine spoil;
2. Ah material placed as a wedge increasing from 0 cm to 30 cm over mine spoil; and
3. raw mine spoil--a mixture of till, soft shale or mudstone and soft sandstone.

The pit surfaces were smoothed in late fall in preparation for early spring seeding. Plots were cultivated to a depth of 5 cm using a tiller disc plow and drill seeded to Hordeum cv. Bonanza at 66.7 kg/ha. Rows were fertilized. Due to the late seeding (June) and poor growing conditions data on straw plus grain yields could not be taken until early October due to the crop immaturity. On Pit #3, the field of Hordeum was not improved by surfacing either material with 15 cm of Ah topsoil. This was attributed to increased competition from volunteer Brassica napus on topsoiled plots which reduced Hordeum yields.

On Pit #2, however, topsoiled plots had significantly higher yields than either subsoiled plots or raw spoils (Table 33.23). Yields from the subsoiled plots were lower than those on the raw spoils. The thicker layer of Ah material (15 to 30 cm) produced significantly more plant matter than the 2 to 15 cm layer. No significant differences in yield were observed for the two subsoil thicknesses.

From these studies McAllister Environmental Services Ltd. (1977a,b) concluded that an Ah layer was, in most cases, helpful in obtaining higher yield and selective mixing of overburden materials would enhance chances for a good yield. They also noted that future cultivation of these plots will cause mixing of spoil and subsoils with top-dress materials, which will probably reduce yields in proportion to the amount of spoil incorporated.

Hodder (1971) compared the production of Triticum aestivum cv. Cheyenne on raw coal spoils (pH 8.6) with that on plots amended with 15 to 20 cm of subsoil or topsoil at the Western Energy Company Mine, Colstrip, Montana. Topsoil and subsoil were placed on the appropriate plots by a scraper, then all plots were disc-harrowed, packed, drill seeded, and fertilized in November.

Table 33.23. Barley yield on mine spoils amended with topsoil or subsoil, Round Hill, Alberta.

Surfacing Material	Thickness (cm)	Yield (kg/ha)
Nil	--	2913
Ah (topsoil)	2 to 15	4650
Ah	15 to 30	5816
Subsoil (B & C horizons)	2 to 30	2219
Subsoil	30 to 60	2162
L.S.D. 5% level		783

Source: Adapted from McAllister Environmental Services Ltd. (1977b). Used by permission of TransAlta Utilities Corporation.

Table 33.24. Triticum aestivum cv Cheyenne forage production (kg/ha) on three soils media, Colstrip, Montana.

Replicate	Topsoil	Subsoil	Raw Spoils
1	19.9	13.7	15.8
2	20.0	9.8	13.7

Source: Adapted from Hodder (1971).

The grain crop was destroyed by a severe hailstorm in June; however, data on forage production were considered retrievable. Topsoiled plots produced the greatest amount of forage compared to subsoil or raw spoils (Table 33.24). Low production on the subsoiled plots was attributed to an atypical subsoil which had unusual physical properties, indicating the need for careful examination of materials to be used for "amending" disturbed areas.

Richardson et al. (1975) and Farmer et al. (1974) studied the effects of topsoiling, irrigation, mulching, and fertilizers at the Decker Coal Mine in south-eastern Montana. Mixes of native, introduced, and native plus introduced species (Table 30.3) were broadcast seeded at 28.6 kg/ha in the fall. The main treatments were topsoiling (20 cm of material), irrigation, and raw spoils. Mulching and fertilization treatments were superimposed on these. Data on dry-weight production were collected in October of the first and second growing seasons.

The reader is encouraged to read the reports to obtain more details on the experimental methods and results. In general, the plots which received topsoil produced greater biomass than control plots under each seed mix and under each subtreatment (Figure 21.1).

Sindelar et al. (1974) and Sindelar, Hodder and Majerus (1973) studied the effects of four topsoil depths on plant growth at the Rosebud Mine, Colstrip, Montana. In the spring of 1972 plots were set up on an east-facing 3:1 slope on newly shaped mine spoils. Topsoil from nearby rangeland was applied to a depth of 0, 5, 10 and 20 cm. Plots were graded, chiselled, fertilized, and drill seeded to Triticum aestivum cv. Cheyenne in April. Plots were sampled for aboveground production at the end of August.

There were very few weeds present in the plots and virtually all production was Triticum. Considerable erosion was observed on non-topsoiled plots. Plant yields increased with the addition of 5 or 10 cm of topsoil (Table 16.23); however, no further increase in yields occurred when 20 cm of topsoil was added. The authors suggested a 10 cm layer of topsoil would be sufficient for successful stand establishment.

In the second growing season the researchers seeded the plots with 45 kg/ha of a broad mixture of perennial grasses, legumes, and shrubs. Plots were again fertilized. Establishment of perennial vegetation was poor on all treatments. Yields of perennial grasses improved with the addition of topsoil but there were no differences among topsoil depths. Volunteer Triticum from the previous season produced the highest dry matter of all species on the plots with 10 cm of topsoil.

Power et al. (1975) have reported on the beneficial effects of topsoil and gypsum placed over several different spoils. The data were collected over a five-year period at several mine sites in North Dakota. Grass species were primarily pure stands of Agropyron desertorum [crested wheatgrass sic], or a mixture of cool-season grasses, mainly A. smithii, Stipa viridula, and A. trachycaulum. A few warm-season grasses were usually seeded in these mixtures (mainly Bouteloua curtipendula and Andropogon scoparius), but they seldom survived. In all instances plots were adequately fertilized. Treatments are shown in Table 33.25.

In highly sodic spoils without topsoil treatment, grass seedings were essentially a failure. With 5 cm of topsoil, such spoils yielded an average of less than two thousand kilograms of dry matter per hectare. On moderately sodic spoils the addition of 5 cm of topsoil improved yield more than the addition of gypsum. For comparison, dry matter yields for native mixed prairie, with and without adequate nitrogen fertilization, produced on undisturbed Grail silt loam at Mandan, North Dakota are given in Table 33.25 for the 1972 to 1974 period. Grass yields on spoils frequently equalled or exceeded those obtained from unfertilized grass on undisturbed soil, but were less than those obtained for adequately fertilized grass on unmined soil.

A 5 cm topsoil layer applied to impermeable, highly sodic coal spoils at the Glenharold Mine at Stanton, North Dakota dramatically improved plant growth and production (Table 33.26; Power, Ries and Sandoval 1976). This trend continued to the end of the third growing season. Barker, Ries and Nyren (1977) tested the effect of 15 cm of

Table 33.25. Average dry matter production for perennial grasses grown on North Dakota strip mine spoils, 1972 to 1974.

Treatment	High SAR[a]	Moderate SAR[a]
Check	78[b] (5)[c]	3730 (3)
5 cm topsoil	1736 (5)	4782 (3)
Check	112 (3)	3730 (3)
Gypsum	426 (3)	4178 (3)
Gypsum + 5 cm topsoil	1366 (3)	4782 (3)

Source: Adapted from Power et al. (1975).

Note: Yield of native prairie on Grail silt loam at Mandan, 1972 to 1974 = 1490 kg/ha without fertilizer, 5197 kg/ha with fertilizer.

[a] High SAR = over 15; moderate SAR = less than 15

[b] production in kg/ha

[c] ( ) = number of years included in mean

Table 33.26. Dry matter production by grass on coal spoils at Stanton, North Dakota with and without 5 cm of topsoil.

	Period	Without topsoil	With topsoil
Dry Weight of Grass (kg/ha)	1973	459	1536
	1974	134	1715
	1975	235	1648

Source: Adapted from Power, Ries and Sandoval (1976).

topsoil on the establishment and growth of 36 species (Table 33.27) also at the Glenharold Mine. Spoils were levelled to a 2 to 3% slope and fertilized. Topsoil was spread on half of the plots to a depth of 15 cm. By the end of the first growing season most species had higher densities on the topsoiled plots. By the end of the third growing season, however, the mean density for each group of species was essentially equal on topsoiled and unamended plots (Table 22.4). Even though plant counts declined on the topsoiled plots, plants remained more vigourous and yields were greater on topsoil.

Ries, Sandoval and Power (1977) have reported on the effects of gypsum and topsoil on growth of Agropyron cristatum sown on sodic spoils in North Dakota. The four basic treatments included: (1) raw spoil (varying in SAR from 1 to 30); (2) spoil treated with gypsum; (3) topsoil; and (4) topsoil over spoil treated with gypsum. Topsoil was applied to a depth of 30 cm and gypsum was applied at a rate of 22 t/ha.

Yield data are presented for the four mine sites in Table 33.28. On the highly sodic spoils (D) topsoil improved yields over the raw spoil or spoil plus gypsum. Best yields on these spoils came with the topspoil plus gypsum treatment. On the spoils with lower SAR values (A to C) the addition of topsoil and gypsum had smaller effects.

Power et al. (1974) also found a minimal increase in yields of Hordeum sown on moderate SAR spoils amended with 5 cm of topsoil and gypsum (Table 33.29). Addition of phosphorus fertilizer had a far greater effect than the topsoil amendment.

On coal spoils near Center, North Dakota, Ries, Sandoval and Power (1978) set up 9 m x 9 m plots to study the effects of surface soil replacement depths (0, 5, 15, and 30 cm) on the establishment of Agropyron cristatum or a native grass mix (35% A. smithii, 20% Stipa viridula, 15% A. trachycaulum, 10% Andropogon scoparius). Grasses were seeded in March at 16.8 kg/ha using a double disc drill with depth bands. One half of each grass plot was broadcast fertilized before

Table 33.27. Common names, scientific names, varieties, and seed sources of revegetation study materials, Glenharold Mine, North Dakota.

Common name	Scientific name	Variety	Source
Cool-season grasses			
Wheatgrasses	*Agropyron*		
Montana	*albicans*	ND-316	SCS Bismarck, ND
Fairway	*cristatum*	Parkway	CA Saskatoon, Sask.
Crested	*desertorum*	Nordan	ARS Mandan, ND
Tall	*elongatum*	Orbit	CS Swift Current, Sask.
Intermediate	*intermedium*	"Commercial"	Pri. Co. Bismarck, ND
Pubescent	var. *trichophorum*	Mandan 759	ARS Mandan, ND
Slender	*trachycaulum*	"Native"	Pri. Co. Healy, KS
Streambank	*riparium*	Sodar	Pri. Co. Healy, KS
Western	*smithii*	Mandan 456	ARS Mandan, ND
Wildryes	*Elymus*		
Altai	*angustus*	-	CA Swift Current, Sask.
Canada	*canadensis*	Mandan wildrye	ARS Mandan, ND
Basin	*cinereus*	ND-718	SCS Bismarck, ND
Mammoth	*giganteus*	Volga	ARS Mandan, ND
Russian	*junceus*	Vinall	ARS Mandan, ND
Beardless	*triticoides*	P-15594	SCS Bridger, MT
Miscellaneous Cool-season grasses			
Creeping foxtail	*Alopecurus arundinaceus*	Garrison	ARS Mandan, ND
Smooth bromegrass	*Bromis inermis*	Mandan 404	ARS Mandan, ND
Prairie sandreed	*Calamovilfa longifolia*	ND-95	SCS Bismarck, ND
Hard fescue	*Festuca ovina* var.*duriuscula*	Durar	SCS Bismarck, ND
Indian ricegrass	*Oryzopsis hymenoides*	Mandan 57-2	ARS Mandan, ND
Nuttall alkaligrass	*Puccinellia nuttalliana*	SD-214	SCS Bismarck, ND
Reed canary grass	*Phalaris arundinacea*	Castor	CA Beaverlodge, Alta.
Alkaki sacaton	*Sporobolus airoides*	ND-264	SCS Bismarck, ND
Green needlegrass	*Stipa viridula*	Lodorm	ARS Mandan, ND
Mandan ricegrass	*X Stiporyzopsis caduca*	Mandan ricegrass	ARS Mandan, ND
Warm-season grasses			
Big bluestem	*Andropogon gerardi*	NDG-4	SCS Bismarck, ND
Little bluestem	*Andropogon scoparius*	ND-387	SCS Bismarck, ND
Sideoats grama	*Bouteloua curtipendula*	Killdeer	SCS Bismarck, ND
Blue grama	*Bouteloua gracilis*	-	ARS Mandan, ND
Deertongue	*Panicum clandestinum*	NY-1325	SCS Bismarck, ND
Switchgrass	*Panicum virgatum*	Mandan 98	ARS Mandan, ND
Legumes			
Crownvetch	*Coronilla varia*	Emerald	SCS Bismarck, ND
Flatpea	*Lathyrus sylvestris*	Wagner	SCS Bismarck, ND
Birdsfoot trefoil	*Lotus corniculatus*	ND-610	SCS Bismarck, ND
Alfalfa	*Medicago sativa*	Semipalitenske	ARS Mandan, ND
Yellow sweetclover	*Melilotus officinalis*	Yellow blossom	Pri. Co. Bismarck, ND

Source: Barker, Ries and Nyren (1977:9-10)

Note: ARS = Agricultural Research Service
SCS = Soil Conservation Service
CA = Canada Agriculture
Pri.Co. = Private Company

Table 33.28. Crested wheatgrass yields (t/ha dry matter) by treatments at four North Dakota mine sites varying in SAR.

Treatment	(A) SAR = 10 to 12	SAR (B)1	(C)12 to 14	(D)25 to 30
Spoil	0.53[a]	1.28[b]	0.56[b]	0.17[b]
Spoil + Gypsum	0.66	1.16	0.71	0.20
Topsoil (30.5 cm)	0.80	1.15	0.76	0.45
Topsoil + Gypsum	0.87	1.18	0.73	0.50

Source: Adapted from Ries, Sandoval and Power (1977).
[a] Average yield for 1974, 1975, 1976.
[b] Average yield for 1975 and 1976.

Table 33.29. Dry weights of barley at heading produced on moderately sodic mine spoils, in North Dakota.

Amendment	Fertilizer Rate (N-P) (kg/ha): 0-0	224-0	0-224	224-224	56-224
Check	196	221	2582	2600	1707
Gypsum	215	154	3124	2745	2147
Topsoil	291	215	2285	1776	2004
Gypsum + topsoil	233	326	2226	1897	1888
Average	234	229	2555	2254	1937

Source: Adapted from Power et al. (1974).

seeding. Density and dry matter production were measured in July of the second and fourth growing seasons.

The spoil material at the experimental site had the following characteristics: silty clay loam texture, pH (water-saturated paste) = 7.5, the saturation extract had an electrical conductivity of 3.0 mmhos/cm at 25°C, 30 meq/L sodium, 3.4 meq/L calcium, 2.0 meq/L of magnesium, and the sodium adsorption ratio was 2.5. The exchangeable sodium percentage correlated with the sodium adsorption ratio. Topsoil used was good quality non-saline and non-sodic A horizon material.

Differences in establishment of A. cristatum and the native seed mix were significant for both years. Depth of topsoil significantly increased plant density and dry matter production for both sets of plots (Tables 33.30 and 33.31). Agropyron cristatum density increased from 23 plants/m^2 for no topsoil to 70 plants/m^2 for 5 cm of topsoil, while density of the native grass mixture rose from 8 plants/m^2 to 70 plants/m^2. Further additions of topsoil did not increase plant density. Average dry matter production significantly increased with the addition of 5 cm of topsoil. A further increase in production was achieved only with the 30 cm layer of topsoil.

Ries, Sandoval and Power concluded that small amounts of topsoil (5 cm) could be used to establish thicker stands of grass where the supply of topsoil is limited. Even though plants can be readily established with minimum replacement of topsoil, restoration of agricultural productivity on sodic spoils requires greater topsoil thickness.

Schuman (1980), Power, Sandoval and Ries (1978), and Power, Ries and Sandoval (1976, 1978) studied the effects of three topsoil thicknesses and eight subsoil thicknesses on the yield of four crops on sodic minespoils (SAR = 26) at Stanton, North Dakota. In 1974, good quality B-horizon subsoil from a productive, cultivated silt loam soil was placed over impermeable sodic spoils to depths increasing from 0 to 150 cm. On top of the subsoil was spread 0, 20 or 60 cm of A-horizon topsoil. A fourth treatment involved mixing topsoil and subsoil in a 1:3 ratio. Each plot was then subdivided and seeded to one of four

Table 33.30. Statistical summary of plant density and dry matter production data for Agropyron cristatum on mine spoil near Center, North Dakota.

Parameter	Mean Value for[a]:					
	Soil Thickness (cm)				Fertilizer	
	0	5	15	30	With	Without
Density plants/m^2	23 a	70 b	72 b	68 b	58 a	58 a
Production kg/ha	5 a	1802 b	1952 b	2596 c	2155 b	1022 a

Source: Adapted from Ries, Sandoval and Power (1978)

[a] Mean values in the same row with different letters differ significantly at the 5% level of probability, according to Duncan's multiple range test.

Table 33.31. Statistical summary of plant density and dry matter production data for native grass mixture on mine spoil, near Center, North Dakota.

Parameter	Mean Value for[a]:					
	Topsoil (cm)				Fertilizer	
	0	5	15	30	With	Without
Density plants/m^2	8 a	70 b	66 b	64 b	54 a	50 a
Production kg/ha	2 a	1065 b	920 b	1313 c	1051 b	635 a

Source: Adapted from Ries, Sandoval and Power (1978)

[a] Means in the same row with different letters differ significantly at the 5% level of probability, according to Duncan's multiple range test.

crops: (1) Triticum aestivum, (2) Agropyron cristatum, (3) Medicago sativa, and (4) a species mix consisting of Bouteloua gracilis, B. curtipendula, A. cristatum, Medicago sativa, and Triticum aestivum.

When high quality topsoil was spread over the subsoil, yields on plots with at least 71 cm of replaced soil were comparable to those on unmined land (Table 33.32). Replacing topsoil and subsoil as separate layers was superior to mixing the two layers.

The authors noted that these are first year data and should be viewed with caution; however, they say it appears that 30 cm of material over sodic spoils would allow restoration of agricultural productivity on mine spoils in North Dakota.

Pole et al. (1979), Bauer, Berg and Gould (1978), and Bauer et al. (1978) examined the effects of topsoil spread over spoils near Beulah, North Dakota. Four thicknesses of topsoil (5, 15, 30, and 60 cm) were spread over levelled, sodic (SAR=10 to 20) coal spoils. Three levels of P were tested on each topsoil plot. Triticum aestivum cv. Waldron was seeded at 1.1 kg/ha in 18 cm spaced rows. Zea mais cv. High-n-Dry (85 day relative maturity) was planted in 91 cm spaced rows and after emergence thinned to a final population of 39 540 plants per hectare.

For all topsoil thicknesses, Zea yields progressively improved during the four years of study except in 1977 when drought conditions decreased the yield. Highest Triticum straw yields were measured in the 60 cm thickness for 1975, 1976, and 1978. The 60 cm topsoil thickness yielded the most Triticum grain for all years measured.

Four-year mean yields, expressed as a percentage of the yield from the 60 cm topsoil thickness, showed increases in yield with topsoil thickness for all crops (Table 33.33). In both Zea and Triticum yields, however, there was no statistically significant difference between the 30 and 60 cm topsoil thicknesses. For this reason the authors concluded that the 30 cm thickness would provide adequate cover and yields on mined land.

Halvorson et al. (1980) studied the effects of three topsoil depths and three fertilizer levels on growth of Triticum aestivum

Table 33.32. Yield (kg/ha) of first harvest of several crops indicating effects of thickness of subsoil and topsoil spread over sodic (SAR=26) mine spoils in North Dakota.

Topsoil Thickness	Subsoil thickness, cm							
	10	30	50	70	90	110	130	150
A. Spring wheat grain yields								
0	800	1062	1196	1290	1263	1250	1317	1250
20	1606	1915	1956	1942	1982	1949	2029	1922
60	1962	2016	2050	2050	1935	2009	2076	2130
Mixed[a]	1055	1344	1472	1505	1559	1478	1512	1452
B. Alfalfa (first cutting)								
0	108	446	805	970	829	691	834	869
20	720	637	1244	1152	1344	1287	1161	1207
60	912	930	980	1044	927	1323	1212	1085
Mixed[a]	128	380	808	952	1233	1057	1144	1217
C. Crested wheatgrass								
0	1956	2498	2897	3039	3368	2769	3465	3194
20	2827	3194	3252	3697	3311	3137	3465	3165
60	2768	2942	3155	3251	3059	3280	2826	3097
Mixed[a]	1587	2498	3349	3252	3524	2980	3291	3368
D. "Native grass" mixture[b]								
0	17	151	118	181	320	272	339	296
20	463	609	871	1026	1048	864	790	656
60	325	133	491	432	366	250	260	314
Mixed[a]	0	7	84	165	103	85	345	349

Source: Power, Sandoval and Ries, (1978:46).

a Topsoil and subsoil mixed 1:3 ratio; for other treatments topsoil spread over subsoil.

b Blue grama (Bouteloua gracilis)and side-oats grama (B. curtipendula).

Table 33.33. Mean corn silage, wheat straw, and wheat grain yields for four growing seasons, expressed as a percentage of the yield from the 61 cm topsoil amended plots, Beulah, North Dakota.

Topsoil thickness	Corn silage	Wheat straw	Wheat grain
5	62.3 c	65.9 b	65.7 c
15	75.7 bc	81.5 b	78.8 bc
30	89.6 ab	98.0 a	92.4 ab
61	100.0 a	100.0 a	100.0 a

Source: Adapted from Pole et al. (1979).

Note: Values followed by the same letter do not differ significantly at the 95% probability level according to Duncan's Multiple Range test.

planted into eight coal overburden materials near Underwood, North Dakota.

Eight trenches 15.2 m wide by 61.0 m long were excavated in the fall of 1978 to a depth of 4.6 m. The eight plots were filled with:

1. compacted gravelly sandy loam (Cgsl);
2. compacted gravelly sandy loam plus clay second lift (Cgsl+c);
3. noncompacted gravelly sandy loam (NCgsl);
4. noncompacted gravelly sandy loam plus clay second lift (NCgsl+C);
5. noncompacted clay loam (NCcl);
6. compacted clay loam (Ccl);
7. nonconcompacted silty clay loam (NCsicl); and
8. compacted silty clay loam (Csicl).

The surface of each trench was covered with either 23, 46, or 69 cm of topsoil to determine the effect of topsoil thickness on plant growth. The trenches were further subdivided for fertility treatments. The plots were disced and planted to T. aestivum on 18 May.

Yields of straw and grain taken in the fall were low, due in part to an unusually dry summer and severe sawfly damage. Increasing the topsoil depth from 23 to 46 cm increased the average Triticum yield from 12.4 to 15.7 hl/ha (Table 33.34). Sixty-nine cm of topsoil increased yields only slightly over the 46 cm depth. Total water in the top 1.2 m of soil increased with increasing topsoil depth in the trenches filled with gravelly sandy loam, but did not increase with topsoil depth in the trenches filled with clay loam and silty loam material. As a result, the trenches filled with sandy loam were much more dependent on topsoil thickness for moisture.

Howard, Schuman and Rauzi (1977) studied the effects of topsoil additions to coal overburden from two Wyoming coal mines, the Wyodak Mine near Gillette and the Seminoe No. 1 Mine near Hanna. Topsoil and newly uncovered overburden were randomly collected, ground and thoroughly mixed prior to the greenhouse studies. Table 33.35 shows

Table 33.34. Effect of topsoil depth on yield parameters of wheat grown on coal spoils near Underwood, North Dakota.

Topsoil Depth cm	Straw Yield t/ha	Grain Yield hL/ha	Stand Height cm	Test Weight kg/hL
23	1.59	12.0	49.0	9.45
46	1.91	15.2	51.6	9.45
69	1.93	15.4	53.1	9.46
Average	1.82	14.2	51.3	9.45

Source: Adapted from Halvorson et al. (1980).
[a] Values are means of three fertilizer levels and eight subsoil materials.

Table 33.35. Pretreatment pH and EC_e of the topsoil and overburden from Wyodak and Seminoe mines, near Hanna, Wyoming.

	pH		EC_e (mmhos/cm)	
Mine	Topsoil	Overburden	Topsoil	Overburden
Wyodak	7.0	7.3	1.00	6.60
Seminoe No. 1	7.5	7.4	0.14	3.95

Source: Adapted from Howard, Schuman and Rauzi (1977).

the pretreatment pH and EC_e of the soils. The seven treatments imposed on each mine soil and overburden are shown in Tables 33.36 and 33.37.

Agropyron dasystachyum cv. Critana and Medicago sativa cvs. Ladak and selection A741 were grown in all treatments. Pots were seeded in February and harvested three times for the grass and five or six times for the legume crop. Soil moisture was kept at optimum levels and temperatures ranged from 12°C at night to 35°C by day.

The addition of topsoil, either as a 5 cm layer or incorporated in a 1:1 mixture gave no significant increase in yields at the Wyodak mine except where fertilized with P or sludge (Table 33.36). However, yields of Medicago at the Seminoe site were significantly improved (Table 33.37).

Howard, Schuman and Rauzi concluded that the effects of topsoil addition were site specific, but that further additions of fertilizers or organic matter were required to significantly improve plant yields.

Aldon, Springfield and Sowards (1976) studied the effects of irrigation on amended coal overburden spoils near Farmington, New Mexico. Three types of overburden were present in the study area. The first was a gray, stoney clay (pH = 7.3, SAR = 27.7); the second was a grayish brown shaley clay (pH = 7.4, SAR = 5.6); and the third a grayish brown sandy loam (pH = 7.3, SAR = 8.8).

Three spoil amendments were applied in long, narrow strips 4.6 to 7.6 m wide: (1) topsoil, applied 15 to 25 cm deep; (2) bottom ash, applied 15 to 25 cm deep, plowed and disced in; and (3) gypsum, applied at the rate of 4.61 t/ha and disced in. Four strips of each amendment were applied at random intervals on each of the test areas.

In the sprinkler irrigation test, plots were seeded with one of the following mixes: (1) Sporobolus airoides and Hilaria jamesii at 2.8 kg/ha each; (2) S. airoides and H. jamesii at 2.8 kg/ha plus Atriplex canescens at 5.32 kg/ha; and (3) S. airoides and H. jamesii at 2.8 kg/ha plus A. canescens and Oryzopsis hymenoides at 4.2 kg/ha. Seeds of S. airoides and H. jamesii were broadcast with a mechanized cyclone seeder, whereas seeds of A. canascens and O. hymenoides were

Table 33.36. Forage yields for alfalfa and grass grown on topsoil amended coal overburden from the Wyodak mine, Wyoming.

Treatments		Forage yield[a] (g)	
		Alfalfa[b]	Grass[c]
1.	Untreated overburden	13.4 c	1.03 d
2.	Topsoil:overburden (1:1 mix)	14.6 c	1.90 cd
3.	Topsoil:overburden (1:1 mix) +		
	67 kg N/ha	--	3.90 cd
	67 kg P/ha	21.2 a	--
4.	5-cm topsoil over overburden	16.3 bc	1.43 cd
5.	5-cm topsoil over overburden +		
	67 kg N/ha	--	4.65 a
	67 kg P/ha	19.4 ab	--
6.	Topsoil:overburden (1:1 mix) + 22.4 t/ha sludge	22.4 a	3.28 b
7.	Topsoil:overburden (1:1 mix) + 22.4 t/ha manure	19.5 ab	2.20 c

Source: Adapted from Howard, Schuman and Rauzi (1977).

Note: Column yields followed by same letter do not differ at 5% level of probability by Fisher's method.

[a] Single plot means from four reps.

[b] Sum of five 1975 harvests on 4/14, 5/21, 6/26, 7/28, 9/2 of Ladak alfalfa (seeded 75 2 14).

[c] Sum of three 1975 harvests on 4/14, 5/21, 9/2 of Critana thickspike wheatgrass (seeded 75 2 14).

Table 33.37. Oven-dried forage yields on soils and overburden from Seminoe No. 1 Coal Mine, Wyoming for seven treatments using 12 cm pots under greenhouse culture.

Treatment	Forage yield[a] (g)	
	Alfalfa[b]	Grass[c]
1. Untreated overburden	13.3 d	2.93 c
2. Topsoil:overburden (1:1 mix)	18.9 c	2.40 c
3. Topsoil:overburden (1:1 mix) +		
67 kg N/ha	--	4.83 ab
67 kg P/ha	31.8 a	--
4. 5 cm topsoil over overburden	17.3 c	3.35 bc
5. 5 cm topsoil over overburden +		
67 kg/ha N	--	6.48 a
67 kg/ha P	25.2 b	--
6. Topsoil:overburden (1:1 mix) +		
22.4 t/ha sludge	24.6 b	5.13 a
7. Topsoil:overburden (1:1 mix) +		
22.4 t/ha manure	25.4 b	6.00 a

Source: Adapted from Howard, Schuman and Rauzi (1977).

Note: Column yields followed by same letter do not differ at the 5% level of probability of Fisher's method.

[a] Single plot means from 4 reps.

[b] Sum of six 1975 harvests on 3/18, 4/23, 5/21, 6/26, 7/28, 9/2 of A741 alfalfa (seeded 74 2 17).

[c] Sum of three 1975 harvests on 3/18, 5/21, 9/2 of Critana thickspike wheatgrass (seeded 74 12 18).

seeded with a rangeland drill. A native hay mulch was then distributed with a mechanized spreader at the rate of 2.7 t/ha and anchored by crimping.

Data on plant emergence were collected in the first growing season and density data were collected in the second season. Both the Oryzopsis and Atriplex had poor emergence and survival and are not reported. Only H. jamesii showed improved emergence in the topsoil amended plots (Table 33.38). Emergence of S. airoides in the ash amended plots was significantly lower than in the other plots. Density for both species was much lower in the second season. Hillaria jamesii again showed greatest density on topsoiled plots. There were also major differences in emergence between the three spoil types.

In the drip irrigation study S. airoides (100 seeds), H. jamesii (80 seeds), and O. hymenoides (80 seeds) were seeded in mid-June in shallow basins under individual emitters. Seeds were covered with 0.6 to 1.3 cm of spoil material, then mulched lightly with straw.

Data on percent stocking were collected in the first and second seasons. Plant responses varied considerably between spoil amendments (Table 33.39); however, the best overall stocking for both seasons was on topsoiled plots. The differences in spoil amendment effects were most pronounced in the plots receiving the least water. Survival on raw spoil was at least as good as that on the bottom ash or gypsum amended plots.

33.4 OTHER GEOGRAPHIC REGIONS

Michelutti (1974) described a study on nickle tailings at Falconbridge Nickle Mines near Sudbury, Ontario that examined the effects of 2.5, 5, 10, and 15 cm topsoil layers on yields of a grass/legume mix in growth chambers. Four locally available soils ranging from sand to loam were selected for testing. Twenty-two t/ha of limestone and 1.1 t/ha of fertilizer were added to soils. After two months, yields were highest on soils amended with 15 cm of black loam

Table 33.38. First year emergence and second year density of Sporobolus aeroides and Hilaria jamesii in amended and unamended spoil materials under sprinkler irrigation near Farmington, New Mexico.

Spoil Amendments	Number of plants per m^2			
	Sporobolus aeroides		Hilaria jamesii	
	1974	1975	1974	1975
Unamended spoil	31.3	6.6	14.2	0.2
Topsoil	30.3	7.7	19.8	0.9
Bottom ash	21.3	7.7	9.7	0.3
Gypsum	35.4	4.7	4.7	0.2

Source: Adapted from Aldon, Springfield and Sowards (1976).

Table 33.39. Percent stocking of plants on coal spoils near Farmington, New Mexico after one and two growing seasons under drip irrigation.

Amendment	Sacaton		Galleta		Ricegrass	
	1974	1975	1974	1975	1974	1975
Spoil	69.5[a]	62.0	70.2	16.5	65.5	66.5
Topsoil	81.0	66.2	81.0	59.7	88.7	86.0
Bottom ash	65.7	52.0	72.2	16.5	77.5	73.2
Gypsum	65.2	30.0	78.2	9.2	70.2	49.2

Source: Adapted from Aldon, Springfield and Sowards (1976).
[a] Values are arithmetic means of four water levels.

(Figure 16.3). Even a 2.5 or 5 cm layer of black loam showed a definite improvement in plant growth over any of the other soils.

On acidic tailings, composed mostly of reddish brown, hydrated iron oxides, Michelutti found that a 5 cm soil cover produced much healthier stands of grasses than those produced on spoil materials. Further studies showed that roots tended to fan out a great deal in the soil cover before eventually penetrating the tailings, and that legumes growing in the 5 cm soil cover had a greater degree of nodulation than plants growing directly in the tailings.

Hodgson and Townsend (1973) tested the ability of several materials to act as substitutes for soil in amending pulverized fuel ash (PFA). They tested subsoil, shale, sewage, peat, and mixtures of these in pot experiments and found that some materials were more effective than soil in establishing a crop of Hordeum vulgare and Avena sativa (Table 33.40). Acidic amendments, such as shale or peat, were very effective as they helped reduce pH and the availability of boron in PFA. Sewage sludge was not an effective amendment due mainly to the unfavorable physical condition of the resulting growth medium.

In contrast, a field trial by the same authors demonstrated that sewage or sewage-shale mixtures substantially improved biennial Brassica sp. and Lolium perenne yields over those achieved by adding similar quantities of topsoil (Figure 33.1). Once the toxicity of ash had been partially reduced, differences between treatments were attributed to the inherent plant nutrient status of the amendments.

Hodgson and Townsend also examined the effects of mixing shallow layers of soil with pulverized fuel ash (PFA) on the yields of Beta vulgaris, Brassica rapa, Brassica oleracea var. acephala, and Brassica hirta. Small additions of soil improved growth and moderate yields were obtained (Table 33.41).

33.5 SUMMARY

The addition of topsoil as an amendment to mine spoil is intended to provide one or more of the following: (1) fertility; (2) renewed microbial activity; (3) improved infiltration; (4) improved

Table 33.40. The effect of bulky ameliorants (50% by volume) on dry-matter yield of barley and oats grown on two types of PFA, England (Results as means of barley and oats).

Ameliorant[a]	Unweathered PFA[b]	Weathered PFA[c]
Sand	1.79[d]	5.30[d]
Loam	4.00	7.88
Acid Shale	4.45	8.38
"Neutral" Shale	3.84	9.85
Peat	7.63	10.01
Sewage (Sludge)	3.41	6.58
Acid Shale + peat	7.12	11.07
Acid Shale + sewage	4.23	9.83
Neutral Shale + peat	6.18	9.50
Neutral Shale + sewage	4.29	9.44
Control (pure loam)	11.91	11.20

Source: Adapted from Hodgson and Townsend (1973).

[a] pH values: sand, 5.7; acid shale, 2.8; "neutral" shale, 6.4; sewage sludge, 5.5; peat, 3.8; and loam, 6.3. Basal NPK applied to all treatments.

[b] pH, 9.2

[c] pH, 8.6

[d] Standard error $\pm$ 0.61.

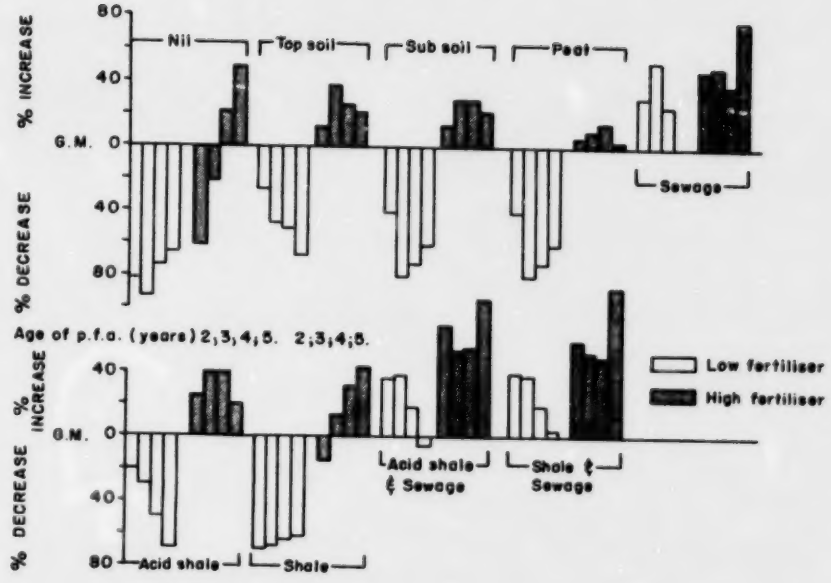

Figure 33.1. The yield of biennial rape (years 2 and 3) and perennial ryegrass (years 4 and 5) on PFA in England treated with 3 inch layers of bulky ameliorants, expressed as a percentage decrease below or increase above the general mean of the experiments for each year.

Source: Hodgson and Townsend (1973)

Table 33.41. Response of fodder beet and white turnip (t/ha) and kale and mustard (100 kg/ha) to topsoil depth, over P.F.A., England.

Treatment	Mean Yield			
	Beet Roots t/ha	Turnip Roots t/ha	Kale 100 kg/ha	White Mustard 100 kg/ha
No soil	14.95	10.27	41.02	28.25
3.8 cm	24.84	42.48	ND	ND
5.1 cm	ND	ND	56.05	31.61
7.6 cm	26.50	23.27	ND	ND
Std. error	±0.32	±0.25	±1.58	±0.17

Source: Adapted from Hodgson and Townsend (1973).

soil stability; (5) improved environment for germination and establishment; and (6) seed source.

Topsoiling has often resulted in greater competition from weed species than generally occurs on raw spoil. This can often offset advantages of topsoiling and illustrates the need to thoroughly evaluate soil properties prior to application.

When other cultural practices are used in combination with topsoiling (fertilization, irrigation) the effect of topsoil may be enhanced or reduced in comparison to the effect of such additional treatments. In such cases the cost/benefit of the individual treatments or treatment combinations must be carefully evaluated.

In the Oil Sands region, peat (muskeg) and overburden (clay materials) are available as amendments to lean tar sands or tailings sands. Additions of peat or peat plus overburden have generally improved germination and productivity of grasses on dike slopes. However, it has been stated that the extra expense of hauling overburden clay material to add nutrients is not warranted and a 1:1 mix of peat and sand is recommended. In addition, high fertilizer rates may be substituted for peat or overburden. Neither of these practices would necessarily result in a self-maintaining system.

Peat mixed with tailing sand appears to be more beneficial than an unincorporated layer of peat. Root penetration increases with depth of incorporation. Deep incorporation has been recommended for erosion prevention; however, other studies have suggested that shallow incorporation will do just as well.

Studies to date have been inconclusive. A well-designed co-operative government/industry program is now under way in the Oil Sands region. This study should provide answers to many outstanding questions.

Results to date from research in mountain areas is similarly inconclusive. Results have shown that agronomic grasses and legumes benefit most from topsoiling in terms of establishment, and biomass and flower production. While results have been similar for native plants, the effects have not been so dramatic.

Raw spoil may provide better microsites, particularly for small seeded species, while surface crusting and erosion can offset the beneficial effects of topsoiling, particularly where it has been packed. As well, fertilizing may mask top-dressing effects. More information is needed on how long the effects of topsoil will last as opposed to fertilized raw spoil.

Some mountain wastes (colluvium, gravel, till) may be successfully revegetated without topsoil and in some cases may serve as top-dressing or be mixed to increase coverage of topsoil. Other wastes such as carbonaceous shale, fly ash, coal waste, bentonitic clay, and grit stone materials may require top-dressing.

Substitute top-dressings include manure, sewage sludge, and sawdust. The relative benefits of these materials have not been adequately assessed. However, availability and cost of materials handling would certainly be of considerable economic importance in their use.

Variations in topsoil thickness is not of obvious immediate importance to germination and establishment of grasses and legumes but may be very critical in terms of ultimate survival and production. This is discussed in more detail in Chapter 16.

Effects of topsoiling in mountainous areas appear to vary considerably with type of spoil, type of "topsoil", species (agronomic versus native and grass versus legume), and treatment of topsoil. Results may, in many cases, be very site specific.

In the Plains region, agricultural crops (cereal grains or forage) are usually the ultimate reclamation crops. Seldom is topsoil preservation and spreading not required. The main problem is the application of sufficient material to establish and maintain productive crops over sodic spoils.

Depths of topsoil applied over raw spoil, or over a subsoil buffer, range from 5 to 69 cm. While early results suggested that 5 to 15 cm of topsoil over spoils with high SAR and EC values would be sufficient, maintenance of productivity is a problem due to upward migration of salts and mixing of spoil and soil through cultivation.

Often yields on such plots, while improved, were not as great as for fertilized natural stands. Results obtained from such shallow topsoil applications appear to be quite dependent upon spoil type and relatively small differences in SAR value and are therefore quite site specific.

More recently, the use of greater depths of topsoil (30 to 60 cm) over raw spoil or use of topsoil over buffer materials (such as till) of considerably better quality than the raw spoil has found greater favour. Topsoil over subsoil is recommended rather than mixing of the two.

Data for up to four cropping years have indicated that 30 cm of topsoil over raw spoil may be sufficient but these results are not conclusive. A general conclusion to date is that minimum depth of topsoil (5 to 10 cm) over spoil is sufficient for crop establishment but restoration of agricultural productivity will require at least 30 cm, probably in addition to a subsoil (or other suitable material) buffer on most severe spoils.

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34. MULCHES AND STABILIZERS FOR ESTABLISHMENT OF GRASSES AND FORBS

A mulch may be defined as "...any non-living material placed or left on or near the soil surface for the purpose of protecting it from erosion or protecting plants from heat, cold, or drought" (USDA, Forest Service 1979). Common mulches are organic fibres (straw, hay, wood-cellulose fibres, wood chips, bark), fabric or mats, rock, and soil (Kay 1978a). These materials differ mainly in the physical characteristics of the individual fibres or pieces. The length of time that a mulch will provide effective site protection is related to its physical characteristics (e.g., colour, roughness; Plass 1978), method of application, physical and chemical properties of the soil, and land-forming or cultural practices (Bennett and Donahue 1975). In general, the longer the fibre the better the mulch (Kay 1978a). No one mulch is suitable for all conditions.

In addition to protecting a site until plants emerge, a mulch may also shorten the time required for establishment of adequate cover (USDA, Forest Service 1979; Kay 1978a). Mulches should be used as an aid in reclamation and not as a substitute for proper fertilization, grading, and shaping for vegetating and stabilizing an area (Plass 1978). Also, the cost of mulches and their application is high compared to seed and fertilizer and so should be used only when necessary (Alaska Rural Development Council 1977; Gallup 1974).

A mulch can aid in establishing plant growth by (USDA, Forest Service 1979; Kay 1978a; Alaska Rural Development Council 1977; Gallup 1974; Coalgate, Akers and Frum 1973; Shears 1971):

1. preventing wind erosion and sandblasting of seedlings by physically protecting aggregates, decreasing wind velocity at the soil surface, keeping the soil moist, and lessening particle movement;
2. preventing water erosion by dissipating the kinetic energy of raindrops, lessening structural destruction, splash erosion and surface sealing, and lessening rill and channel erosion;

3. facilitating infiltration by allowing water to be absorbed more slowly and uniformly by the underlying soil;
4. inhibiting evaporation which may also slow upward movement of salts through spoils and/or soils;
5. providing a warm, moist, shaded microclimate around the seed, thus optimizing germination;
6. reducing the chance of seedlings being frost heaved by creating a heat trap around the roots;
7. protecting seeds from rapid temperature change and direct sunlight, and protecting seedlings from sunlight reflected by light coloured tailings;
8. possibly adding desired seeds;
9. acting as a weed control mechanism in shrub or row plantings;
10. acting to hold seed in place;
11. possibly supplying a limited amount of plant nutrients; and
12. re-inoculating micro-organisms into mined spoils and providing them with a source of carbon and energy

There are several potential disadvantages to using mulches (USDA, Forest Service 1979; Kay 1978a; Packer and Aldon 1978; Plass 1978; Gallup 1974; Wellin 1974; Currier 1973; Schwendiman 1973; McCreery 1971; Shears 1971):

1. As mentioned previously, they are expensive.
2. If an organic mulch has a carbon to nitrogen ratio of much greater than 25:1, it could potentially cause nitrogen deficiencies because the micro-organisms attacking that organic matter are much more efficient in using any inorganic nitrogen that is in the soil than are the plants. Thus, these micro-organisms tend to decrease the availability of inorganic nitrogen and leave a

deficiency for a short time. Included among mulches that have a very high carbon to nitrogen ratio are straw and wood waste materials. The same principle can be applied to phosphorus and sulphur.

3. Mulches high in nitrogen could produce a high ammonium concentration around germinating seedlings that could be toxic. Some organic mulches (such as some hardwood bark residues and paper products) have substances that can be toxic to seedlings in some circumstances. For example, Kay (1979) has shown a significantly lower percent emergence of Bromus mollis grown on soils mulched with high boron paper (Figure 34.1).
4. Mulches can cause slow germination and plant growth due to lower temperatures or water immobilization. This commonly occurs when too much mulch is added.
5. Mulches may attract unwanted organisms such as insects, fungi, diseases, and rodents. For example, Excelsior can attract mice, which then eat the seeds or seedlings as they come up.
6. Unknown amounts of seed may be introduced by the use of straw, hay, peat, or topsoil mulches resulting in severe competition with seeded or planted species.
7. Some mulches (straw or hay) are susceptible to blowing off in windy areas and therefore require the addition of a tackifier. Using hay with well developed seed heads provides additional cohesiveness.
8. The application of mulches requires skilled operators or problems may develop. For example, Stephenson (1974), found that the depth of a straw mulch applied to the soil surface was extremely important. He found that a 3.8 cm layer provided the best germination conditions. Anything less than 2.5 cm caused slow germination and anything over 7.6 cm seemed to stop germination completely.

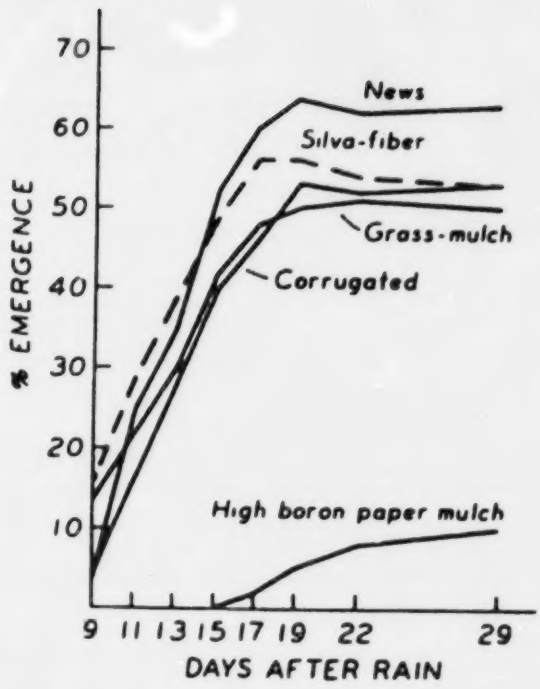

Figure 34.1. Percent emergence of Bromus mollis under natural rainfall conditions. Mulches applied at 2,240 kg/ha over top of seed. Emergence is similar with all products except one containing boron at 6,000 ppm.

Source: Kay (1979)

9. Mulches on dry sites or dark mulches may cause premature germination of seeds by providing warmth and moisture. These seedlings then die off due to insufficient moisture for further growth.
10. When seed is mixed with mulches in hydroseeders the seed often becomes suspended in the mulch with no mineral soil contact, thus reducing survival. It is recommended that seed be sprayed initially with mulches being applied afterwards to cover seed

The USDA, Forest Service (1979), Kay (1978a,b) Bennett and Donahue (1975), and Nebauer and Good (1971) have produced detailed reviews on various mulches used in aiding reclamation of disturbed lands. The reader is encouraged to obtain these articles for further information. Table 34.1 shows the advantages and disadvantages of several commonly used mulches. Techman Ltd. (1979) have reviewed uses of mulches and provided product specifications for several mulches and stabilizers available in Canada and the U.S.

Kay (1978a,b), and Bennett (1975) provided the following general discussion of various mulches.

The choice of mulch treatment or product is determined by: (1) site characteristics (e.g., size, shape, slope, aspect, precipitation, temperature, wind); (2) species of plants to be seeded and their requirements for germination, seedling emergence, and establishment; (3) availability of products; (4) costs; (5) need for special equipment; and (6) effectiveness. Economically, straw and hay provide best results in terms of both protection and encouragement of plant growth if resulting weeds or fire hazards are not a problem. Hydraulic mulching provides a weed-free mulch of low fire hazard, with potential labour-saving in application. Wood residues such as bark or wood chips are easier to apply, longer lasting, and less susceptible to blowing or fire than straw or hay. Disadvantages are that they may easily discourage plant growth if applied at excessive rates, may reduce

Table 34.1. Advantages and disadvantages of commonly used mulches.

Type of mulch	Advantages	Disadvantages	Comments
Crop residue: Straw or hay	Generally most economical Usually satisfactory under many circumstances.	Weed seeds usually present; even hay seeds may be considered a weed on a particular site. Straw may "wick-out" moisture from soils in very dry conditions, thus resulting in poor germination and seedling establishment.	Anchor mulch, especially on slopes by crimping, or using plastic meshes, jute, chemical tackifiers. Long-stemmed best, especially for crimping. Uniform application important. Generally, 4.5 t/ha adequate. In Utah, it was found that rotovating mulch 15 to 20 cm into soil increased grass seedling survival. Can be spread with modified farm manure spreader.
Native grasses: prairie hay	Adds desirable native species seeds to area and mulches at same time.	May harvest weeds along with native species.	
Wood residues: sawdust, woodchips, bark, shavings	Protects surface. Adds organic matter. No weed seeds. More fire resistant than straw. Long lasting. Easy to apply. Chips resistant to wind movement.	Shavings and sawdust blow. Nitrogen deficiency. Packing may occur resulting in less aeration. May float on running water. May prevent precipitation from reaching soil.	Chips: 4.5 t/ha usually adequate; chip size, 1.3 to 0.05 cm.
Plastic film	Excellent vapour barrier. Good weed control. Light-coloured, perforated, found effective in New Mexico: soil temperature in summer -7.8°C lower than in soil with no mulch.	Labour intensive High cost.	Information on temperature effect varies. Colour is important because of reflection, absorption.
Fibre tackifiers and soil binders	SBR Styrenebutadiene and SS Super Slurper have been found to be very absorbent and thus help provide water.	Quite expensive. Must be applied correctly in order to have maximum effectiveness. With SBR Styrenebutadiene and SS Super Slurper premature germination may occur. In high wind areas, it can solidify, break into pieces and blow away.	Typically added into water carriers; can also be added with seed slurries. 561 to 1121 kg/ha solids usually sufficient, dilution rates of 5:1 to 7:1 optimum.
Rocks, gravel, pebbles	Effective at specific sites. Are permanent -- do not disintegrate.	Smaller than 0.2 cm in diameter not good for wind erosion.	Choose sizes greater than 0.2 cm in diameter. Must nearly cover entire ground surface, 2.5 to 5.1 cm thick is effective control (303 t/ha = about 2.5 cm depth).
Mixtures	Add micro-organisms to soil over short and long term. (Ex.: straw and bark)		

Continued

Table 34.1. Concluded.

Type of Mulch	Advantages	Disadvantages	Comments
Hydraulic mulching	Labor costs low. Typical green colour allows operator to get uniform distribution. Hydromulching and hydroseeding can be done at the same time, if it is impossible to do the two operations separately. Wood cellulose fibre mixed with seed and fertilizer can be sprayed on steep slopes.	Of little value unless it adheres to the soil surface and remains intact during rainstorms, wind. Hydromulch with fibre improves germination, but does not improve production. When hydromulch and hydroseeding are done together, seeds may not have adequate soil contact.	Application rate of 1682 kg/ha appears adequare for most situations; may need more for quite steep slopes. May need to add N to hydromulch to compensate for C:N ratio of mulch chosen. Always put some seed in mulch. Hydroseeding and hydromulching together should be reserved for special cases when moisture is sufficient to keep the seed moist for 2 to 3 weeks after seeding.
Fabric or mats: jute, excelsior, woven, paper, plastics, nets	Especially useful on steep slopes. Nets good in high wind areas.	Expensive: 4 to 5 times more than tacked straw. High labour input for anchoring. Not effective on rough surfaces or rocky areas. Erosion from beneath may be a problem.	Used only on limited critical areas because of cost.
Manure and sewage sludge	Can protect soil surface and adds nutrients, such as N, P, K, S.	When used alone, it becomes wet, then dry, can lose much of N through volatilization of ammonia.	Needs 11, 22, 34 t/ha order to protect soil. On bentonite spoils, a grass establishment study showed that an application of wood chips as mulch and sewage sludge as N supplier was more effective than a high application (400 parts per million) of inorganic N.
Asphalt	Rapid-curing asphalt keep straw and other materials in place. Slow-curing asphalt allows for growth of seedlings before it cures. Coats surface, remains intact 4 to 10 weeks. A stabilizer for straw. Nonporous, and conserves water underneath it. Some plants react positively to it.	Nonporous, thus causes surface water to run off. Some plants react negatively to it.	Make decision based on type of asphalt (slow, medium, rapid curing) desired. Make decision based on reaction to asphalt by plant species desired. 11223 L/ha an average application. Typically, heated and spread by spraying. Apply from top of slope down, so impermeable caps are built on clods of soil down the slope, leaving sides free for seedlings to come out of and to absorb water.
Resin emulsion in water	More porous than asphalt. Insoluble in water. Resistant to weathering.		5612 L/ha good against wind erosion. Often considered superior to asphalt.
Latex emulsion	Resistant to erosion.	Limits water penetration. Some studies indicate it is less effective than some other mulches.	

Source: Adapted from U.S. Forest Service (1979)

pH if material is strongly fermented, and are less effective per unit weight than straw. Fabrics and mats may be very effective if properly anchored; however, excessive erosion beneath the mat may occur on rough surfaces. Mats also require labour intensive application.

Soil mulches may be obtained simply be leaving a rough seed-bed or by benching steep slopes during construction. They are very effective, often inexpensive, and may avoid premature germination caused by other mulches in the absence of adequate moisture for continued growth. Gravel mulches reduce erosion, encourage invasion of indigenous plants even on very dry sites, and are permanent.

Kay (1978a,b), Plass (1978), and Bennett and Donahue (1975) have reviewed the uses, advantages, and disadvantages of soil stabilizers in reclamation work. The use of stabilizers on drastically disturbed sites is a relatively recent development and has been restricted due to the high cost of application. The following summary has been taken primarily from Plass (1978:332).

Chemicals to be used as a mulch, humectant (a substance that absorbs moisture or helps another substance retain moisture), or soil binder are usually applied in a water carrier or as part of a hydraulic seeding slurry. "Most of them infiltrate no more than the upper 2.5 cm of soil and bind the soil particles together to form an erosion-resisting crust. Others form a thin film on the surface that provides temporary protection against soil movement.

"Soil stabilizers are often classified by their basic formulas, e.g., polyvinyl acetates, acrylic copolymers, elastomeric emulsions, and natural vegetable gums. Similar products may differ from each other because of additives mixed with basic formula. These additives may affect curing time, crust durability, and moisture infiltration rates.

"There are many products available for use as soil stabilizers. Due to the large number of products on the market and the variations among products that have a similar basic formula, a discussion of soil stabilizers may become quite complex. Variables which may influence the effectiveness of stabilizers are (1) dilution

rate with water, (ii) soil properties and climatic conditions, and (iii) amendments added to the solution to aid in establishing vegetation....

"...One advantage of soil stabilizers is that all the materials required to establish a vegetative cover can be applied in one operation, [see Bayles and Dudley (1976)], whereas, for many mulches, application of seed and fertilizer must precede application of the mulch.

"A secondary benefit from the use of soil stabilizers is a reduction in seed loss because of surface runoff; the soil stabilizer holds the seeds in place until they germinate. This fact is particularly important on extremely steep slopes. It has also been observed that soil stabilizers reduce friction in the hydromulcher's pipelines, pumps, and application hoses, thus reducing wear on these vital parts and making application of the slurry more efficient....

"...[One problem with soil stabilizers is that they] usually require more precise preparation before application than do mulches.... [Another problem is that the] tough crust [formed by some stabilizers] can physically restrict the emergence of some plant species. Small-seeded grasses and legumes may have difficulty in penetrating tough crusts; large-seeded species of grasses would probably be less affected....[Therefore] selection of species for seeding may be important when some soil stabilizers are used." Bennett and Donahue (1975) suggested using slow-curing stabilizers to allow time for grass seedlings to break through the film. A rapid-setting stabilizer should be used to tack straw mulches. The tough crust may also reduce water infiltration, thus reducing plant establishment in low-rainfall areas. Asphalt films are virtually non-porous, and consequently seeds may fail to germinate if insufficient soil moisture is present before application.

"An attractive alternative to separate treatment with a mulch or a soil stabilizer utilizes a combination of a wood fibre or wood cellulose mulch and a soil stabilizer. In this combination, the

desirable characteristics of the materials complement each other. Low rates of application of the combination should provide site protection comparable to that achieved by a high rate of either product used alone. There is evidence that the effective life of a wood fibre or wood cellulose mulch is extended when it is used in combination with a soil stabilizer.

"Many stabilizers may also be used as chemical tacks to hold straw, hay, or other lightweight mulches in place. The chemical stabilizer binds the individual pieces of mulch together and increases the resistance of the material to the movement of wind or water. The strength of the bond and the effective life of the treatment depend on the amount of soil stabilizer applied."

34.1 NORTH-EAST (OIL SANDS) REGION

No mulch studies have been reported for the Oil Sands region; however, information from similar situations may have application in that area. Zak (1977) examined the establishment and survival of grasses seeded on mulched sand dunes at Provincetown, Massachusetts. Twelve grasses were drill seeded to a minimum depth of 5 cm into the windward side of an inland dune. Each grass species was mixed with Avena sativa, seeded in May, and the plots were fertilized. Nine mulch plots and a control plot were set up in duplicate. Mulches were applied the day after seeding.

Germination success and plant survival were assessed qualitatively in June 1962, and May 1963, respectively (Table 34.2). Zak felt that mulches did not significantly enhance grass establishment or moisture conditions under the climatic conditions of the first growing season. He noted that there was little difference in available moisture at the 10 cm depth between mulched and unmulched plots. By the following spring most of the mulches had deteriorated except the hay, jute, and asphalt.

Mitchell (1974) tested several soil stabilizers in an attempt to reclaim sand dunes in Australia. He found that some, such as

Table 34.2. Rates of application and evaluation of various mulch materials as related to plant emergence and survival on sand dunes near Provincetown, Massachusettes (E=Excellent; G=Good; F=Fair, P=Poor; N=Nothing).

Mulch materials	Rates/a	Plant emergence 23 June 1962	Plant survival 22 May 1963
Asphalt emulsion[b]	756 L	P	P
Asphalt cutback[b]	756 L	P	N
Elastomeric polymer emulsion[c]	315 kg	P	P
Polyvinyl acetate copolymer[d] +	262 L		
ammonium sulfate	25 kg	E	G
Polyvinyl alcohol solution[d]	1140 L	G	G
Sodium silicate +	250 L		
ammonium sulfate	90 kg	E	G
Gelatin	450 kg	P	N
Hay	900 kg	P	N
Heavy jute mesh[e] opening	1.9 cm	E	G
Check (no mulch)	---	E	G

Source: Adapted from Zak (1977).

a) 1 acre = .404 6856 ha.

b) Asphalt emulsion (Agricultural mulch E.A.P. 2005) and asphalt cutback -- Esso Research and Engineering Co., Linden, N.J., supplier.

c) Elastomeric polymer emulsion (Soil Set) -- Alco Oil and Chemical Corp., Philadelphia, Pa.

d) Polyvinyl acetate copolymer (gelva Emulsion T.S. 70) and Polyvinyl alcohol solution (gelvatol 1-60) -- Shawinigan Resin Corp., Springfield, Mass.

e) Heavy jute mesh -- Ludlow Textile, Ludlow, Mass. supplier.

bitumen, oil-latex emulsion, bitumen stabilized mulch, and disced-in straw were effective but the cost of preparation, application, and materials discouraged widespread use.

34.2 MOUNTAINS AND FOOTHILLS REGION

Takyi (1980) studied the effects of three roll-out mulch mats on the establishment of grasses on an abandoned coal mine near Cadomin, Alberta (elevation = 1675 m). Plots were located on a 15° slope with a west-southwest aspect. Spoils were a highly pervious and erodable mix of sandstone, siltstone, shale overburden, and some coal.

The seed mix, comprised of Festuca rubra (40% by weight), Trifolium repens (12%), Phleum pratense cv. Climax (24%), and Poa compressa cv. Canon (24%), was broadcast by hand in each plot at a rate of 60 kg/ha, and plots were fertilized. Both the seed and fertilizer were raked into the spoil in a single operation on 07 June.

Immediately following seed application, the roll-out mats were applied according to the manufacturers' recommendations. The treatments were: (1) no mulch (check); (2) ridging (ridges constructed across the slope, spaced at 1 m, and with a trough bottom to ridge crest height of 0.22 m); (3) jute net (Ludlow Soil Saver, Type #48--heavy mesh); (4) Excelsior blanket (AMXCO "Curlex"); and (5) Hold/gro (the standard seeding type for slopes, ditches, waterways, and dormant seeding).

Percent cover and dry matter production were measured 29 August. The Hold/gro treatment was clearly superior to the other treatments (Table 34.3) in terms of plant cover produced at the end of the first growing season. Plant cover on all three mulched plots was greater than that on either the ridged or control plots. Dry matter production was low in all treatments; however, the Hold/gro mulched plots produced significantly more material than the other treatments.

Takyi noted that while plants could not effectively penetrate the Hold/gro and grow above it in the first growing season, the plants still received enough sunlight so that growth did not seem to have been affected. The higher dry matter production under the Hold/gro was

Table 34.3. Percent cover, dry matter production and erosion rating for three mulch treatments, and a ridging treatment, Cadomin, Alberta.

Treatment	Plant Cover (%)	Production (g/m^2)	Erosion Rating[a]
No mulch	41.8	48.4 a	3.00
Ridging-trough	66.7	50.4 a	--
Ridging-trough & ridge	33.2	100.8 bc	0.33
Jute net	55.5	56.0 a	0.25
Excelsior blanket	67.0	61.6 ab	0.0
Hold/gro	92.0	125.6 c	0.0

Source: Adapted from Takyi (1980).
Note: Means in column followed by a common letter are not significantly different at the 5 percent level by Duncan's Multiple-Range Test.
[a] Erosion rating: 3=light to moderate, 0=nil to very minimal.

attributed to better spoil moisture status, and especially to the "greenhouse micro-environment" created at certain times under the mat. From these first year results Takyi felt that Hold/gro would be a valuable reclamation tool in northern regions.

Macyk (1974, 1975) compared burlap, Leno-mesh, and Huls 801 (a soil stabilizer) as mulches on coal spoils in Grande Cache, Alberta. The mulches were tested on three sites: (1) a 44° slope with a loose soil surface, (2) a north-facing 25° slope, and (3) a 42° slope. The burlap and leno-mesh were secured with 13 cm nails and weighted down with rocks. The Huls 801 was applied at the rate of 500 mL/m^2.

Plots were seeded with a mixture of Agropyron cristatum cv. Fairway, Elymus junceus cv. Sawki, Bromus sp. cv. Carlton, Festuca rubra cv. Boreal, and Medicago sativa cv. Rambler, and fertilized.

Best growth occurred under burlap, followed by Leno-mesh, and then the soil stabilizer. The burlap was effective because it held the seed on the slope, retained moisture, and kept the surface moist and cool during hot weather. A major disadvantage to burlap and Leno-mesh was the high cost.

The second growing season was wetter than the first resulting in increased plant growth. Under these conditions the Leno-mesh was superior to the burlap as it has a coarser weave which allowed easier penetration by germinating seedlings.

Rothwell (1978) has examined the suitability of logging debris as a mulch for vegetation establishment and erosion control along forest roads in Alberta. The technique, called "brush mulching", involves spreading logs, tree tops, and branches uniformly over a surface to intercept and slow overland flow and to trap sediment.

A grass/legume seed mixture of 30% Festuca rubra, 30% Trifolium pratense, 20% Lolium perenne, and 20% Secale cereale was broadcast seeded at 9 kg/ha onto brush mulched or unmulched plots near stream crossings.

The brush mulch consisted of logs 2 to 15 cm in diameter, tree tops, and branches. The debris was laid on the ground parallel to the contour and across the expected drainage. The average size of the sites

treated was 6 ha. The brush mulch was applied by hand to road shoulders, ditches, and backslopes in one to two days. Debris was spaced 60 to 120 cm apart, the closer spacing being on steep areas such as backslopes, and was "anchored" in place by driving a tractor over it to push it partially into the ground. Seeding in late May and fertilization followed mulching. A total of nine roadstream crossings were treated and studied. Five crossings were mulched, seeded, and fertilized; four received no mulch.

Results from the study indicate that a mixture of brush mulch and grass was more effective in trapping sediment than a grass cover alone. Average sediment production in the first year after treatment, from the mulched sites, was four to five times less than that at crossings with only a grass cover. Most of the differences are attributed to the logging debris because the grass on all sites was small and sparse, after the first growing season.

The logging debris was also beneficial in preventing grass seed from being washed away. The distribution of grass on the mulched sites was more widespread than on unmulched sites, and was greatest on the uphill sides or edges of logging debris. Grass cover on the unmulched sites was sparse and occurred in small surface depressions or in the bottom of small rills. The brush mulch also appeared to hasten germination and promote better growth of grass. Germination and growth of grass occurred one to two weeks earlier on mulched sites than on unmulched sites.

In the second year differences between treatments were more pronounced. Grass cover on the mulched sites was more dense and uniform in distribution than on unmulched sites. Sediment production from the mulched sites decreased by six times that observed in the first year. Sediment production on the unmulched sites, however, did not decrease by any noticeable amount in the second year after treatment.

Rothwell (1978) concluded that brush mulching was an effective short-term erosion control measure which provides small microclimatic sites favourable to grass germination and growth. The grasses became more important in erosion control once the sediment trapping capacity of

the debris was exceeded. A further advantage of the brush mulch was that it was readily available.

Tests of several mulches for erosion control in the Swan Hills area of Alberta were performed by Zacharuk (1974), Goff (1971), and Wyldman (1971). The authors tested Turfibre, straw and asphalt, sawdust and asphalt, jute mesh, straw and plastic netting, Aquatain, and brush mulches and found all to be satisfactory for improving growing conditions and stabilizing soil while vegetation became established. The major differences between mulches were cost, availability, and ease of applicaton.

The Turfibre process, in which seed, asphalt, emulsion, fertilizer, and mulch were applied by hydroseeder, was adaptable to large scale operations where equipment access was possible. All three authors found brush mulch to be the most attractive because material was readily available and could be easily and economically spread.

Carr and Ballard (1980) tested the effectiveness of Jacklin organic mulch and Terratack I binder for erosion control along forest roads on Vancouver Island, British Columbia. Two sites with steep (70 to 90%), easily eroded slopes were chosen for the study. The Koksilah site, on erodible, fine textured till material with a thin clay layer 1.5 to 1.8 m from the surface, receives 180 cm of precipitation per year. The Caycuse site receives over 250 cm of precipitation annually. The predominant soil material is a very clayey glacial till.

The study used a randomized block design with four blocks at Koksilah and two at Caycuse. Each block contained four hydroseeding treatments and an unseeded control. The hydroseeding treatments were a combination of one- and two-step applications of seed and fertilizer, and a mulch (Table 34.4).

Plots were seeded with the following grass/legume mix and evaluated for percent cover in mid-April: Phleum pratense, Agrostis alba, Lolium perenne, L. multiflorum, Dactylis glomerata, Festuca rubra, F. arundinacea, F. ovina, F. rubra var. commutata, Trifolium repens, T. pratense, T. hybridum, and Lotus corniculatus.

Table 34.4. Hydroseeding treatments on two forest roadside sites; Vancouver Island, British Columbia.

	Treatments and Specifications	
Treatments		
1-Step	Seed + fertilizer + binder	Seed + fertilizer + binder + mulch
2-Step	Seed + binder, followed by fertilizer + binder	Seed + binder, followed by fertilizer + binder + mulch
Specifications		
Seed rate	100 kg/ha	Special mix
Mulch	670 kg/ha	Jacklin organic mulch
Fertilizer	450 kg/ha	10-30-10
Binder	11 kg/ha (without mulch) or 33 kg/ha (with mulch)	Terra tack 1

Source: Adapted from Carr and Ballard (1980).

There were no significant differences in total plant cover established among the different application methods (Table 34.5); however, the one-step application procedure resulted in germination of fewer legumes. Carr and Ballard suggested that this may be due to prolonged contact between seed and fertilizer, which may have harmful effects on seed germination. From the results of this study the authors concluded that the use of a mulch and binder did not warrant the extra expense incurred.

Hodder (1970) evaluated several mulches for erosion control along highways in Montana. North and south exposed slopes with a 2.5:1 gradient, all recently topsoiled, were staked into 15.2 m wide plots, cultivated with a Klodbuster, broadcast seeded, and Klodbustered again to cover the seed. Eleven mulch treatments (Table 34.6) were applied within plots on the seeded roadsides.

Treatments were visually assessed for soil stabilization effectiveness at the end of the first and second growing seasons based on the following criteria:

1. eroded sediment accumulation at the base of plots reflecting mulch erosion control efficiency;
2. amount of desirable permanent vegetative cover produced; and
3. amount of temporary invading cover produced.

Soil stabilization was much better on the north exposure (Table 34.6); however, there were no clearly superior mulches in this experiment. Salts in the chemical fertilizers tended to destroy the binding qualities of the Gelgard. The two straw treatments lost effectiveness by the second season. The major objection to the straw mulch was the invasion of weeds during the second growing season.

Jensen and Hodder (1979) performed two experiments to assess the effectiveness of mulches on establishing vegetation along highways near Melrose, Montana (elevation = 1600 m). The study area was located on a large backslope with a north-south orientation, west exposure, and a 5:1 slope ratio. Subsoil exposed by the backslope consisted of a complex pattern of randomly oriented layers of medium size particles of

Table 34.5. Percentage of plant cover on two forest roadside sites, Vancouver Island, British Columbia.

Block	Replicate	Treatment[a]				Average[b]
		No Mulch		Mulch		
		One-step	Two-step	One-step	Two-step	
Koksilah						
Cut-slope	1	50	40	40	45	44 a
	2	35	50	45	60	48 a
Sidecast	1	75	80	75	75	76 b
	2	65	85	65	90	68 b
Caycuse						
Cut-slope	1	70	70	65	65	68 b
	2	85	40	90	60	69 b
Average		63 c	61 c	63 c	66 c	

Source: Adapted from Carr and Ballard (1980).

[a] No plant cover existed on control plots.

[b] Averages followed by the same letter are not significantly different according to Duncan's Multiple Range Test at the 0.05 level of probability.

Table 34.6. Comparison of 12 mulching treatments for soil stabilization effectiveness, Montana.

Treatment	Northern Exposure		Southern Exposure	
	Fall 1968	Fall 1969	Fall 1968	Fall 1969
Straw with Asphalt Binder	2[a]	5	1	7
Straw Stubbled	1	7	1	8
Asphalt (SS-1 RC)	3	4	3	6
Silva-Fiber (Green)	4	3	4	6
Silva-Fiber (Black)	4	3	3	5
Gelgard with Silva-Fiber (Green)	2	3	2	6
Gelgard with Silva-Fiber (Black)	4	3	3	5
Dacagin with Silva-Fiber (Green)	5	3	2	6
Dacagin with Silva-Fiber (Black)	5	3	2	6
Coherex with Silva-Fiber (Green)	ND	ND	2[b]	6[b]
Aquatin	ND	ND	7	8
Seeded Check Plot	9	6	8	8

Source: Adapted from Hodder (1970).

[a] Rating scale 1 to 10 (1-Best). Values are means of three reps, rounded off to nearest whole number. ND = No data.

[b] Values are means of two reps only.

sand, gravel-sand mixtures, and clay. The roadside cut was covered with a 10.2 cm layer of topsoil salvaged from the adjacent roadway prior to road construction. Topsoil was characterized as loam and the subsoil as sandy loam.

In July 1973, fertilizer was applied and a chisel plow was used to till the study area twice, in opposite diagonal directions. Two separate study designs (Location I and II) were each established as randomized block designs with three replications for each treatment.

Table 34.7 shows the grass, legume, cereal grain, and shrub seed mixture. The perennial species seed mixture was broadcast seeded at 21 kg pure live seed (P.L.S.) per hectare and the annual species, Hordeum vulgare cv. Horsford, was broadcast seeded at 13 kg P.L.S./ha.

The following day, the plots designated for the straw stubble mulching treatment (Location I) were broadcast seeded and covered with a layer of good quality Hordeum straw blown on at a rate of 3360 kg/ha with a pneumatic mulcher. The straw was crimped into the soil with a mulch tiller. The remaining mulch plots were then broadcast seeded and lightly harrowed with a tractor drawn harrow to ensure adequate seed coverage. A pneumatic mulcher was employed to apply 3360 kg/ha of Hordeum straw bound together with 2805 L/ha of SS-1 type asphalt. On 23 July a hydroseeder was used to apply the wood-fibre and paper mulches at rates of 1680 kg/ha (Location II). Plots receiving the gouging treatment were broadcast seeded immediately following gouging in order to take advantage of the seed coverage potential of the recently disturbed soil. Plots were irrigated once or twice in the growing season.

In September 1973, July 1974, and September 1975, percent ground cover and density of Hordeum, grass, legume, and shrub seedlings were recorded. Results from the first season for the plots at Location I, comparing straw stubble and straw plus asphalt to an unmulched control, are presented in Table 34.8.

Jensen and Hodder (1979) found that straw stubble mulch, although rather difficult to apply, is unique in that it provides both above soil surface micro-environment modification and subsurface soil

Table 34.7. Melrose, Montana study seed mixture.

Common Name	Scientific Name	Seeding rate (kg/ha P.L.S.)
Streambank wheatgrass	Agropyron riparium	2.2
Fairway crested wheatgrass	Agropyron cristatum	2.2
Slender wheatgrass	Agropyron trachycaulum	2.2
Durar hard fescue	Festuca ovina var. duriuscula	2.2
Lincoln smooth brome	Bromus inermis	1.1
Russian wildrye	Elymus junceus	2.2
Orchard grass	Dactylis glomerata	2.2
Ranger alfalfa	Medicago sativa	2.2
Lutana cicer milkvetch	Astragalus cicer	2.2
Fourwing saltbush	Atriplex canescens	2.2
Horsford barley	Hordeum vulgare	13.4

Source: Adapted from Jensen and Hodder (1979).

Table 34.8. Mean percent plant cover and seedling densities per 0.5 m^2 circular sample for four seed-bed treatments, each irrigated at two intensities (heavy = +, light = -) at the Melrose, Montana study area. Treatments seeded July 19, 1973 and sampled November 27, 1973.

Treatments[a]	Total % Cover		Seedling Densities							
			Barley		Perennial Grasses		Legumes		Total	
	+	-	+	-	+	-	+	-	+	-
Control	45.2 cx	29.1 yc	10.2 d	10.4 c	39.5 b	30.5 b	14.0 b	14.9 b	64.4	56.6
Straw 3363 kg/ha plus Asphalt 2805 L/ha	62.9 abx	38.1 yb	17.6 bc	19.7 a	26.8 c	11.3 a	14.6 b	9.6 c	60.1	41.3
Straw stubble 3363 kg/ha	66.8 ax	41.5 ya	20.9 a	22.0 a	29.3 c	28.0 b	11.9 b	16.6 a	62.9	68.0
Gouging	57.1 abcx	36.4 yb	15.2 c	15.7 b	54.0 a	37.5 b	21.4 a	18.7 a	91.9	73.1

Source: Adapted from Jensen and Hodder (1979)

Note: Treatment means in columns followed by different letters (a through d) and treatment means in rows followed by different letters (x and y) within data groups, are different from each other at the 0.05 level (Newman-Keul test). Those groups of means not followed by letters indicate that the analysis of variance was not statistically significant.

stabilization. This treatment established a more dense stand of Hordeum as compared to the control treatment, and produced a greater percent foliage ground coverage the first season; however, the treatment did not provide a consistently significant advantage for perennial plant establishment. This agrees well with the results of Hodder's earlier work in which straw was extremely effective in the first season but lost effectiveness in the following year (Hodder 1970). The mulch was very effective for controlling erosion and for capturing and holding blowing soil.

The stands established with the straw plus asphalt mulch lacked uniformity because of inconsistent mulch depths caused by difficulty in applying the straw uniformly and by wind moving the straw around after its application.

No one mulch was consistently better than the others; however, the straw stubble seemed to provide a slight edge in many cases. The small differences in total cover and density of legumes and perennial grasses in mulched plots as compared to the unmulched plots indicate the short-term benefits of the mulch may not be worth the extra expense.

Results from the third season for the plots at Location II, comparing straw plus asphalt, wood-fibre, and paper as mulches, are presented in Table 34.9.

The straw plus asphalt treatment produced significantly lower total cover and perennial grass density by the end of the third growing season. The wood-fibre and paper mulches did not significantly improve total cover over the controls. Cover, and to a greater extent plant density, was reduced on all plots during the three growing seasons.

As in the first study the straw plus asphalt mulch was not effective because of inconsistent mulch application. The paper mulch was difficult to handle and did not control erosion very well, although it produced some of the best stands. The wood-fibre mulch did not significantly improve plant establishment but controlled erosion well.

From these two studies Jensen and Hodder (1979:77-78) concluded that:

Table 34.9. Mean percent cover and plant densities per 0.5 m^2 circular sample for four seed-bed treatments at the Melrose, Montana study area. Treatments were seeded July 19, 1973, irrigated for initial establishment, and sampled September 27, 1975.

Treatments[a]	Total % Cover	Plant Densities			
		Barley	Perennial Grasses	Legumes	Total
Control	48.2 a	ND	11.2 b	5.4 a	18.2 a
Straw 3366 kg/ha plus Asphalt 2805.9 L/ha	30.1 b	ND	7.7 c	5.0 a	13.6 a
Wood-fibre 1682 kg/ha	49.3 a	ND	11.3 b	5.8 a	19.0 a
Paper (Tinex) 1682 kg/ha	51.2 a	ND	14.0 a	6.9 a	22.7 a

Source: Adapted from Jensen and Hodder (1979)

[a] Treatment means in columns followed by different letters are significantly different from each other at the 0.05 level (Newman-Keul test).

1. "The use of straw stubble mulch is highly recommended because it conserves significant amounts of soil moisture, provides both surface and subsurface soil erosion protection, provides a protective soil surface microenvironment for developing seedlings, persists for two to three years and has consistently developed desireable stands of perennial vegetation."
2. "Wood-fibre mulches should be applied at a minimum rate of 1680 kg/ha and only on stable slopes, allowing the material to bind together as a continous mat."
3. "Straw plus asphalt mulch should be used only if it can be applied in a uniform manner and on an area where the straw particles will permanently remain in place. The most important advantage in using straw plus asphalt is that it effectively conserves soil moisture. The major disadvantages of the mulch are that if it is applied too thick the developing seedlings are smothered and if applied too thin it provides little benefit for plant establishment or erosion control."

Brown and Johnston (1978) transplanted approximately 5300 grass plugs in September on a 0.3 ha plot on copper-gold-silver spoils at the McLaren Mine, Montana (elevation = 3300 m). Plugs were planted in rows contouring the slope on a grid pattern of 0.6 m between rows, and plants. A surface mulch of 2500 kg/ha of straw, tacked with water- soluble asphalt, was blown onto half of the transplant area. An effort was made to avoid thick accumulations of straw on the surface that might act as an excessive heat trap or barrier to seedling emergence. The entire plot area had been limed (2200 kg/ha), and fertilized. The three amendments were then incorporated into the surface 15 cm with a spring-tooth harrow pulled by a dozer.

Percent survival, production, growth, and development (Table 26.8) of the transplants were evaluated at the end of the following growing season. Brown and Johnston (1978) noted that the apparent depressant effect of the mulch was unexpected. Field data

revealed that 80% of all transplant mortality occurred in the mulched portion of the study area. One possible explanation for this was that the field season was considerably cooler and wetter than normal and it was felt that the mulch may have maintained suboptimum temperatures for growth near the soil surface. The authors suggested that the effects of a mulch would be quite different in warmer, drier years.

In reclamation studies on the revegetation of processed oil shales near Grand Valley, Colorado, Bradshaw (in Bloch and Kilburn 1973) tested the effectiveness of five "soil covers" or mulches on establishment of Agropyron elongatum. A trench was excavated to a depth of 0.9 to 1.2 m and filled with TOSCO II processed shale. The material was then compacted to a degree similar to the surrounding soil and the surface was spaded and leveled in preparation for planting.

Five types of soil covers were tested: (1) straw, (2) rock dust, (3) burned shale, (4) Ludlow Soil Saver, and (5) sawdust which were spread on each bed after planting. Ludlow Soil Saver is a dyed green cloth of 1.3 cm jute fibres woven 1.3 cm apart in both directions. Its large, soft fibres help to hold moisture and prevent erosion.

Seeds were planted 0.6 to 0.3 cm deep. All plots received a small amount of all-purpose fertilizer and were given abundant water.

The plots that were covered with Ludlow Soil Saver performed well. The plot covered with straw supported limited growth. The soil cover probably helped to retain water near the surface, cooled the surface by shading, and thus reduced evapotranspiration. Initial results with the sawdust were encouraging; however, most of it blew away during the unusually windy spring, indicating that sawdust used as a surface cover was not a good mulch in this area.

Bradshaw concluded that Ludlow Soil Saver was an effective mulch for revegetating processed oil shales. Sawdust provided a good mulch but was not considered useful in windy locations.

Farmer, Richardson and Brown (1976) studied the effects of topsoiling, irrigation, fertilization, and mulching on the establishment and growth of three grass/legume mixtures (Table 33.17) sown onto a

copper-cobalt mine in central Idaho. The mulch was a sphagnum peat moss applied at 5.6 t/ha and held in place by a single layer of jute netting.

The reader is encouraged to obtain the report for a more detailed description of the methods. The reader should also consult Richard et al. (1975) and Farmer et al. (1974) for similar studies in Plains areas.

Emergence data were collected in the first year and production data in the second year. On the control plot, mulch significantly increased production and emergence of all mixtures when combined with fertilizer (Figure 30.1).

On the top-dressed plots there was a significant difference in seedling emergence due to mulch but the effect varied with species mix. Mulch decreased emergence of the introduced and the native plus introduced mixtures, while it had no effect on the native mix. Mulch had no significant effect on plant production (Figure 30.1). No emergence data were collected for the irrigated plots. Mulch had a significant positive effect on plant production on fertilized plots only (Figure 30.1).

From these preliminary data the authors concluded that topsoiling appears to be an important amendment but that mulching, especially on topsoiled plots, may not be necessary for plant establishment.

Czapowskyj and Sowa (1976) studied the effects of mulching, liming and fertilization on the survival and growth of Coronilla varia cv. Penngift transplanted onto anthracite coal refuse in Pennsylvania.

The experimental site was on the plateau top of a coal-breaker refuse pile. The refuse was composed of fragmented carbonaceous rocks associated with coal seams but separated from coal in a cleaning plant. The material consisted of 75 percent shale fragments and coal pieces larger than 2 mm and 25 percent of material smaller than 2 mm. The material retained 2.4 cm of available water per 30 cm depth. The pH ranged from 3.7 to 4.0. The site was practically level, somewhat compacted, and devoid of vegetation.

The treatments consisted of all combinations of three levels of hydrated lime, three levels of 5-10-5 fertilizer, and two levels of straw mulch (0 and 1 bale of about 22.7 kg per plot). Lime and fertilizer were applied with a calibrated seed and fertilizer spreader shortly after the spring thaw. The mulch was spread by hand after planting.

In the spring, 25 two-year-old C. varia crowns, each including 20 to 25 cm of taproot, were hand-planted with a mattock at 0.6 x 0.6 m spacing in each treatment. In the spring of the second season, three more blocks were planted in the same manner. Survival and cover data were taken for three growing seasons. Ground cover only was measured in later years.

Lime was the most important factor in establishment of the C. varia. Straw mulch did not appear to increase survival or growth and any beneficial effects of the mulch had largely disappeared by the third growing season (Tables 34.10 and 34.11). Czapowskyj and Sowa concluded that mulch provided some benefit in establishing ground cover; however, lime was much more important.

Dean et al. (1973) studied the erosion control potential of several stabilizers on saline copper tailings in Utah. In the first experiment, five chemical stabilizers were applied to newly erected and seeded tailings mounds. The five stabilizers tested were: (1) Coherex (a resinous adhesive); (2) Orzan A (ammonium lignin sulfonate); (3) Rezosol; (4) DCA-70 (elastomeric polymers); and (5) a cationic neoprene emulsion. After 28 weeks, seedling survival studies showed that almost 40% more seedlings grew on the Coherex-treated plots than on the control. In comparison, the cationic neoprene emulsion treatment supported only 50% as many seedlings as the control plot, Orzan A only 70%, and Rezosol and DCA-70, 90%. Thus Coherex appears to mitigate the deleterious effect of salinity on seedling establishment and survival.

In the second study, a series of indoor tests were made in which Medicago sativa cv. Ranger, Agropyron cristatum, Melilotus officinalis, Chrysothamnus sp., Artemisia sp., and Lycopersicon esculentum cv. Marglobe were planted in leached and unleached tailings

Table 34.10. Percentage survival of crownvetch planted on anthracite coal-breaker refuse, Pennsylvania. (Average of three replications.)

Growing season	Fertilizer applied (kg/ha)	Lime application rate (t/ha)					
		0		5.6		11.2	
		No mulch %	Straw mulch %	No mulch %	Straw mulch %	No mulch %	Straw mulch %
Planted in 1965							
1	0	15	21	89	95	92	97
2	0	0	8	79	88	87	92
3	0	0	1	75	88	83	92
1	280	11	15	83	95	84	93
2	280	1	8	79	89	80	80
3	280	0	4	72	87	79	80
1	561	5	11	89	92	85	88
2	561	1	1	84	92	79	88
3	561	0	0	81	92	79	88
Planted in 1966							
1	0	8	1	48	55	65	67
2	0	1	1	41	55	57	67
3	0	0	1	41	55	57	67
1	280	3	0	60	53	56	52
2	280	0	0	49	52	44	51
3	280	0	0	49	52	44	51
1	561	3	2	55	68	74	74
2	561	0	2	54	68	74	74
3	561	0	2	54	68	74	74

Source: Adapted from Czapowskyj and Sowa (1976)

Table 34.11. Percentage of ground cover produced by crownvetch planted on anthracite coal-breaker refuse, Pennsylvania.

Growing Season	Fertilizer (kg/ha)	Lime application rate (t/ha)					
		0		5.6		11.2	
		No mulch	Straw mulch	No mulch	Straw mulch	No mulch	Straw mulch
Planted in 1965							
1	0	<1	<1	4	10	6	8
2	0	0	<1	5	8	4	9
3	0	0	0	10	20	13	19
4[a]	0	ND	ND	ND	ND	ND	ND
5	0	0	0	55	65	55	70
6	0	0	0	75	80	75	85
7	0	0	0	80	85	80	85
1	280	<1	<1	5	17	7	13
2	280	0	<1	5	13	7	10
3	280	0	<1	12	27	14	20
4[a]	280	ND	ND	ND	ND	ND	ND
5	280	0	0	55	80	60	65
6	280	0	0	80	95	80	90
7	280	0	0	85	95	80	90
1	561	<1	<1	7	12	6	12
2	561	<1	0	6	10	5	11
3	561	0	0	15	25	15	23
4[a]	561	ND	ND	ND	ND	ND	ND
5	561	0	0	70	75	70	70
6	561	0	0	80	90	90	90
7	561	0	0	90	90	90	90

Continued

Table 34.11. Concluded.

Growing Season	Fertilizer (kg/ha)	Lime application rate (t/ha)					
		0		5.6		11.2	
		No mulch	Straw mulch	No mulch	Straw mulch	No mulch	Straw mulch
Planted in 1966							
1	0	<1	<1	2	3	2	3
2	0	<1	<1	6	11	7	13
3	0	0	<1	21	34	25	32
4	0	0	0	45	70	50	70
5	0	0	0	75	90	70	80
6	0	0	0	80	90	85	85
1	280	<1	0	1	2	1	2
2	280	0	0	6	9	5	9
3	280	0	0	28	31	20	28
4	280	0	0	50	55	35	55
5	280	0	0	80	80	65	80
6	280	0	0	80	85	80	85
1	561	0	<1	2	3	2	3
2	561	0	<1	11	16	11	17
3	561	0	<1	43	48	48	51
4	561	0	0	70	75	70	75
5	561	0	0	85	80	80	85
6	561	0	0	90	90	90	90

Source: Adapted from Czapowskyj and Sowa (1976)

[a] No measurements taken.

which had been treated with several chemical soil stabilizers. In leached tailings, a control and four plots treated with Coherex, Soil Gard, Peneprime, and Compound SP-400 were set up. In unleached tailings a control and two plots treated with Coherex and Soil Gard were established. Coherex and Soil Gard stimulated germination and sustained plant growth; Peneprime and SP-400 hindered germination under the conditions tested. On leached tailings, the effects of Coherex and Soil Gard were nearly the same. On unleached tailings, Coherex performed better than Soil Gard (Table 34.12).

Other indoor tests were made in which the germination and survival rates of Hordeum vulgare, Melilotus offinalis, Medicago sativa, Agropyron cristatum and Lycopersicon esculentum cv. Marglobe were tested in leached and unleached tailings treated with Coherex, fertilizer amendments (P_2O_5 and urea). On both tailings, the effect of Coherex plus fertilizer was pronounced. On leached tailings germination rates (after 12 days) were 40 to 56% (compared to only 4% with fertilizer alone) and 20 to 34% on unleached tailings.

In outdoor tests Dean et al. (1973) found reduced germination rates for Coherex amended plots as compared to indoor tests. This was attributed to the higher temperatures on the dark coloured Coherex plots as compared to the cooler indoor environment.

Green, Woodruff and Blaser (1973) reported results from 11 experiments which assessed the effectiveness of various mulches applied on highway construction sites in Virginia. Four experiments were designed to assess fall and winter erosion control abilities and the rest investigated mulches and tacking agents for summer turf establishment. Data from these studies are presented in Tables 34.13 to 34.23. The reader is encouraged to read the report for further details on site characteristics, methods, and sampling procedures.

In general, studies on fall and winter stabilization indicated that a straw mulch with a tackifier was superior to wood-fibre (Tables 34.13 to 34.16) in terms of erosion control and plant establishment. Straw was also generally superior to other mulches for summer seedling establishment (Tables 34.17 and 34.23). However, in

Table 34.12. Germination and survival rates in percent for treated copper tailings in Utah.

Tailings	Coherex		Soil Gard	
	Germination	Survival	Germination	Survival
Leached	64.1	61.0	54.7	52.6
Unleached	30.5	16.0	14.5	5.6

Source: Dean et al. (1973).

Table 34.13. A comparison of wood-fibre versus a curasol AE binder for turf establishment with a fall seeding. Rt. 40, Gretna, Virginia, established 06 October, 1971.

Treatments[a] rate/ha	Soil cover (%)			Plants/m^2			Erosion estimates[c]		
	Dec.2'71	Mar.22'72	June 6'72	Dec.2'71	Mar.22'72	June 6'72	Dec.2'71	Mar.22'72	June 6'72
A Wood-fibre (WF), 1682 kg	50.8 a	72.0 a	88.3 a	1220 a	583 a	ND	2.6 ab	3.5 b	ND
B Curasol AE, 701 L	53.5 a	75.8 a	92.0 a	1231 a	583 a	ND	2.1 a	2.7 a	ND
C Curasol AE, 374 L + WF 1682 kg	31.0 b	51.2 b	70.5 b	842 b	302 b	ND	2.9 b	4.0 c	ND

Source: Adapted from Green, Woodruff and Blaser (1973:15)

[a] This area was uniformly seeded (kg/ha) with Ky 31 fescue 44.8, annual ryegrass 5.6, redtop 2.2, sericea lespedeza 44.8, fertilizer included 1680 kg/ha of 10-20-10 and 840 kg in spring 1972, with 1344 kg hydrated lime at seeding.

[b] Figures in the same column not marked by the same small letter are significantly different ($P \leq 0.05$). Reported for plants/m^2 as plants/ft^2.

[c] Erosion estimates were made on a 0 to 10 basis with 0 = nil and 10 = severe rill and sheet erosion.

Table 34.14. Effects of several mulches on winter erosion control and percent soil cover with vegetation during winter and early spring, 1972. I-64, James City County, Virginia, established 02 December, 1971.

Mulch Treatment[a]	Erosion Rating[b]		Soil Cover (%)[c]	
	Jan.31	Apr.12	Jan.31	Apr.12
Wood-fibre, 2242 kg/ha[c]	2.6 b	4.3 f	29 ab	30 c
Wood-fibre, 2242 kg/ha, Curasol AE, 935 L/ha	2.6 b	2.9 e	26 ab	37 b
Wood-fibre, 2242 kg/ha, tacked with RC-250 asphalt 2806 L/ha	2.3 b	2.4 cd	38 a	46 b
Wood-fibre, 2242 kg/ha, tacked with RC-250 asphalt 5612 L/ha	1.9 b	1.9 bc	45 a	46 b
Straw, 4484 kg/ha, tacked with RC-250 asphalt 2806 L/ha	0.6 a	1.1 ab	42 a	62 a
Straw, 4484 kg/ha, tacked with RC-250 asphalt 5612 L/ha	0.3 a	0.6 a	45 a	62 a
RC-250 asphalt (alone) 11 224 L/ha	1.8 b	2.5 cd	11 b	14 d
Check (no mulch)	4.0 c	7.7 f	10 b	13 d

Source: Green, Woodruff and Blaser (1973:16)

[a] The area was seeded uniformly (kg/ha) with Ky 31 fescue 56, redtop 1.7, annual ryegrass 5.6, Abruzzi rye 44.8, Penngift crownvetch 22.4, and sericea lespedezi 67. Fertilizer was applied at 1121 kg/ha of 10-20-10 and limestone at 4484 kg/ha.

[b] Erosion ratings: 0 to 10 basis with 10 being most severe erosion. Figures in columns not followed by the same letter are significantly different.

[c] The north facing slope had nearly 100% crownvetch cover in October 1973, and the south facing slope had about 70% cover of grass, sericea, and crownvetch.

Table 34.15. Erosion control and turf establishment during winter with wood-fibre and straw mulches with binder additives. Rt. 693, Montgomery County, Virginia, established 13 January, 1972.

Mulch treatment[a] (rates /ha)	Erosion Rating[b]		Plants/m^2		Soil cover (%)	
	May 10	June 9	May 10	June 9	May 10	June 9
Check (no mulch)	1.5	2.0	32 cd	108 c	3	25
Wood-fibre, 2242 kg	0.8	1.0	32 cd	97 c	5	25
Wood-fibre, 2242 kg plus RC-250 asphalt, 1870 L	0.5	1.0	54 c	11 c	5	30
Wood-fibre, 2242 kg plus RC-250 asphalt, 3740 L	0.3	0.5	43 cd	97 c	5	25
Wood-fibre, 2242 kg plus RC-250 asphalt, 5610 L	0.2	0.3	54 cd	97 cd	5	25
Wood-fibre, 2242 kg plus Curasol AE, 561 L	0.7	0.9	43 cd	86 cd	4	20
RC-250 asphalt 5610 L alone	0.6	0.8	32 cd	43 cd	2	15
Straw, 4484 kg plus RC-250 asphalt, 1870 L	0.4	0.5	11 b	475 b	25	80
Straw, 4484 kg plus RC-250 asphalt, 3740 L	0.2	0.4	378 a	551 a	30	90
Wood-fibre, 2242 kg plus 467.5 L cutback asphalt[c]	1.0	1.8	22 cd	54 cde	2	15
Wood-fibre, 2242 kg plus 935 L cutback asphalt	1.1	1.5	11 d	32 de	1	10
Wood-fibre, 2242 kg plus 1870 L cutback asphalt	0.7	1.0	11 d	11 e	1	5

Source: Adapted from Green, Woodruff and Blaser (1973:18)

[a] The area was seeded uniformly with a mixture (in kg/ha) of Ky 31 fescue 84, redtop 1.7, annual ryegrass 8.4, and crownvetch 22.4; fertilizer included 1680 kg/ha 10-20-10 and 3360 kg/ha limestone.

[b] Erosion ratings were made on a 0 to 10 basis.

[c] Cutback asphalt consisted of a 1:1 ratio of kerosene and RC-250 asphalt.

Table 34.16. Effects of several tacking agents with straw and wood-fibre mulches on winter erosion control and subsequent spring grass stands. Rt. 658, Nelson County, Virginia, established February 3, 1972.

Mulch Treatment[a] (rate/ha)	Erosion Control[b]		Grass (Plants/m^2)		Soil Cover (%)	
	Apr. 13[c]	July 14	Apr. 13	July 14	Apr. 13	July 14
Check (no mulch)	3.7 a	4.0 a	68.0 b	310.0 c	2 b	52 c
Wood-fibre, 2242 kg	2.8 b	3.0 b	248.4 b	424.4 bc	6 b	65 bc
Wood-fibre, 2242 kg plus 1871 L RC-250 asphalt tack	2.6 b	2.9 b	176.0 b	392.0 bc	6 b	55 c
Wood-fibre, 2242 kg plus 3741 L RC-250 asphalt tack	1.5 c	1.9 bc	294.8 b	504.4 b	8 b	57 c
Wood-fibre, 2242 kg plus 748 L Aerospray 72 tack	2.9 ab	3.2 b	202.0 b	415.8 bc	5 b	62 c
Wood-fibre, 2242 kg plus 748 L Curasol AE tack	2.7 ab	3.0 b	299.2 b	506.5 b	5 b	60 c
Wood-fibre, 2242 kg plus 374 L Landlock	2.9 ab	3.3 b	197.6 b	447.1 b	6 b	63 c
Straw, 4484 kg plus 1871 L RC-250 asphalt tack	1.2 c	1.6 c	1047.6 a	932.0 a	18 a	87 ab
Straw, 4484 kg plus 3741 L RC-250 asphalt tack	0.8 c	1.2 c	1414.9 a	1020.6 a	21 a	95 a

Source: Adapted from Green, Woodruff and Blaser (1973:20)

[a] This area was uniformly seeded with Ky 31 fescue 89.7 kg, redtop 2.2 kg, annual ryegrass 8.4 kg, and Penngift crownvetch 22.4 kg/ha. Fertilizer application included 2242 kg/ha hydrated lime and 1121 kg/ha of 10-20-10 at seeding plus 560.5 kg/ha 10-20-10 in spring 1972.

[b] Erosion ratings were made on a 0 to 10 basis with 10 being most severe.

[c] All figures in columns not marked by the same small letter are significantly different ($P<0.05$). Reported for grass as plants/ft^2.

Table 34.17. The influence of several organic mulches and chemicals used alone and with mulches on grass, crownvetch populations, and on soil erosion for a summer seeding. Rt. 232, Radford, Virginia, established August, 1972.

Mulch Treatments[a] (rates/ha)	Seedlings/0.19 m^2 (October 17, 1972)[b]				Erosion Estimates[d]	
	Mulch + Grass		Mulch + Crownvetch			
	Alone	WF1682 kg/ha[c]	Alone	WF1682 kg/ha	Alone	WF1682 kg/ha
Check	35 cd	ND	0.5 b	ND	1.4	ND
Straw and asphalt	179 a	ND	10.5 a	ND	0.1	ND
Wood-fibre (WF) 1682 kg	100 bc	ND	1.0 b	ND	0.9	ND
Wood-fibre 3363 kg	83 bcd	ND	1.5 b	ND	0.6	ND
Curasol AE 701 L[e]	20 d	81 bcd	0.0 b	1.5 b	0.8	0.8
Aerospray 673 L, 701 L	8 d	76 bcd	0.0 b	0.5 b	0.4	0.2
Aquatan, 89.7 kg	36 cd	117 ab	0.5 b	1.5 b	0.6	0.3
Erocom, 4484 kg	55 bcd	ND	0.0 b	ND	1.2	ND
Colloidal Product, 701 L	13 d	67 bcd	0.0 b	0.5 b	1.0	0.5
Landlock, 701 L	ND	102 bc	ND	3.0 b	ND	0.3

Source: Adapted from Green, Woodruff and Blaser (1973:22)

[a] The area was uniformly seeded with Ky 31 fescue 67.3, redtop 1.7, annual ryegrass 5.6, and crownvetch 16.8 kg/ha with one half of each mulch treatment receiving German millet 8.4 kg/ha. All plots received 2242 kg/ha of hydrated lime and 1682 kg/ha 10-20-10 before seeding.

[b] Figures for the same measurement not marked by the same small letter are significantly different, $P = 0.01$.

[c] Alone-mulch treatments as indicated in left column; WF1682 kg/ha-mulch treatments as indicated in left column plus wood-fibre at 1682 kg/ha.

[d] Erosion estimates are on a 0 to 10 basis, 0 = nil and 10 = severe rill and sheet erosion.

[e] All chemical binders were applied with water at a dilution of 3.8 L (1 gal) or 0.5 kg (2 lb) of binder to 379 L (100 gal) of water.

Table 34.18. The influence of several organic mulches and chemicals on early grass and crownvetch populations and soil erosion for a summer seeding, near Moore's Building and Supply, Christiansburg, Virginia. Established August 1972.

Mulch Treatments[a] (rates/ha)	Seedlings/0.19 m^2 [b] (October 27, 1972)				Erosion Estimates[d]	
	Mulch + Grass		Mulch + Crownvetch			
	Alone	WF1682 kg/ha	Alone	WF1682 kg/ha	Alone	WF1682 kg/ha
Straw 4484 kg + asphalt 1403 L	365 a	ND	20.5 a	ND	0	ND
Erocom, 4484 kg	148 bc	ND	1.8 bcd	ND	0.3	ND
Wood-fibre (WF) 1682 kg	135 bcd	ND	2.3 bcd	ND	0.5	ND
Landlock, 701 L	109 cdef	70 efg	1.5 bcd	0.5 cd	0.4	0.2
Aerospray 673 L, 701 L	85 defg	116 cdef	1.3 bcd	2.3 bcd	0.3	0.1
Curasol AE, 701 L	61 fg	172 b	0.3 d	2.8 bc	0.3	0.2
Wood-fibre #4076 binder 1682 kg	79 defg	ND	1.0 bcd	ND	0.4	ND
Check	60 fg	ND	0.3 d	ND	0.8	ND
Aquatain 84 kg	45 g	121 bcde	0 d	3.0 b	0.2	0.3
Colloidal product 701 L	36 g	121 bcde	0.3 d	2.3 bcd	0.5	0.3

Source: Adapted from Green, Woodruff and Blaser (1973:24)

[a] The area was uniformly seeded with Ky 31 fescue 67.3, redtop 1.7, annual ryegrass 5.6, and crownvetch 16.8 kg/ha with one half of each mulch treatment receiving German millet 8.4 kg/ha. All plots received 2242 kg/ha of hydrated lime and 1681.5 kg/ha 10-20-10 before seeding.

[b] Figures for the same measurement not marked by the same small letter are significantly different, $P = 0.01$.

[c] Alone=mulch treatments as indicated in left column; WF1682 kg/ha=mulch treatments as indicated in left column plus wood-fibre at 1682 kg/ha.

[d] Erosion estimates are on a 0 to 10 basis, 0 = nil and 10 = severe rill and sheet erosion.

[e] All chemical binders were applied with water at a dilution of 3.8 L (1 gal) or 0.5 kg (2 lb) of binder to 379 L (100 gal) of water.

Table 34.19. The influence of wood-fibre and chemical soil binders on vegetation establishment and soil moisture of a "rough" graded slope. Floyd County, Rt. 639, Virginia, 05 June, 1973.

Mulch applied (rates/ha, binder: water)	Weeping Lovegrass[a]							
	Soil Cover (%)				Height (cm)		Soil Moisture (%)	
	July 12, 1973		Aug. 11, 1973		July 12, 1973		July 12, 1973	
	Alone	WF841[b]	Alone	WF841	Alone	WF841	Alone	WF841
Landlock 67 kg (1:10)	26	23	50	57	10.4	11.4	5.2	11.9
Landlock 134.5 kg (1:10)	9	11	50	47	7.6	9.7	9.2	7.4
Petroset 56 kg (1:30)	12	12	52	75	6.4	9.1	6.1	7.3
Petroset 129 kg	8	ND	25	ND	8.9	ND	6.8	ND
Genaqua 112 kg (1:25)	6	16	37	60	7.4	7.6	7.9	7.7
Polyvinyl alcohol 224 kg (1%)	13	15	38	82	10.9	6.4	10.7	9.7
Straw @ 2242 kg	21	ND	80	ND	8.4	ND	10.4	ND
Wood-fibre 1681 5 kg	38	ND	75	ND	12.7	ND	8.1	ND
Tinex 1681.5 and 841 kg	21	13	60	62	9.7	10.7	7.6	10.5
Check	19	ND	54	ND	9.1	ND	7.1	ND
Check, all of plot seeded	18	ND	60	ND	13.5	ND	7.5	ND
Ecology Control 168.2 kg (1:20)	11	ND	32	ND	8.1	ND	6.9	ND

Source: Adapted from Green, Woodruff and Blaser (1973:25)

[a] The bottom one-third of each plot was seeded uniformly with a mixture of Ky 31 fescue 44.8, weeping lovegrass 11.2, and crownvetch 11.2 kg/ha. Fertilizer at the rate of 1121 kg/ha of 10-20-10 was applied before seeding.

[b] Alone = mulch treatments as indicated in left column; WF841 indicates mulch treatments as in left column plus 841 kg/ha (750 lbs/acre) of wood-fibre.

Table 34.20. The influence of chemical stabilizers and organic mulches on soil erosion and plant establishment on a cut slope. Rt. 60, Powhatan, Virginia, established 27 June, 1973.

Mulch Combinations[a] (Rates/ha)	Erosion Ratings[b,c]		July 13, 1973			Soil Cover (%)
			Plants/m^2		Height (cm)	
	July 5	Aug. 1	Grass	Legumes	Grass	Aug. 1
Straw 3363 to 4484 kg + Landlock 1122 L	10.0 a	10.0 a	1879	400	4.6	53 ab
Genaqua 935 L, WF 841 kg	10.0 a	9.3 ab	886	97	1.8	8 d
Petroset 468 L, WF 841 kg	9.0 ab	7.8 bcd	1404	356	3.8	67 a
Petroset 1076 L, WF 841 kg	8.8 ab	8.0 bc	896	140	2.5	49 abc
Landlock 1684 L, WF 841 kg	8.5 ab	7.3 cd	421	43	1.8	8 d
Landlock 1122 L, WF 841 kg	8.0 abc	7.0 cde	896	205	2.5	27 bcd
Aquatain 224 kg + WF 841 kg	9.8 a	7.0 cde	346	76	2.5	14 cd
Tinex (448 kg dry weight) 1682 kg dry weight	5.5 def	6.3 cde	410	86	1.8	25 bcd
Ecology Control 179 kg, WF 841 kg	6.8 bcd	6.0 de	572	22	1.8	16 bcd
Polyvinyl Alcohol 1871 L + WF 841 kg	6.0 cde	5.3 ef	194	65	2	7 d
Wood-fibre (WF) 1682 kg	2.5 g	3.5 fg	1102	281	3.1	26 bcd
Landlock 561 L, WF 841 kg	3.8 efg	3.3 g	508	43	1.8	12 cd
Wood-fibre (WF) 841 kg	3.5 fg	3.0 g	734	97	2.3	20 bcd
Landlock 1122 L	3.3 fg	2.5 g	86	0	2.3	17 bcd
Check	2.0 g	2.5 g	86	0	2.3	11 cd

Source: Adapted from Green, Woodruff and Blaser (1973:28)

[a] Before applying mulch combinations the bottom one-third of each plot received a uniform application of seed (Ky 31 fescue 50 kg/ha, weeping lovegrass 11 kg/ha, sericea lespedeza 45 kg/ha, crownvetch 22 kg/ha) and fertilizer (1121 kg/ha of 10-20-10).

[b] Erosion ratings are 1 = very severe, 10 = no erosion, 8 to 10 = satisfactory, 5 to 7 = marginal, below 5 = unacceptable.

[c] Means in a column followed by the same letter are not significantly different at the 5% level of probability.

Table 34.21. Estimated soil loss and erosion on a sandy fill slope after applying various chemical stabilizers and organic mulches. Rt. 638, Suffolk, Virginia, established 13 June, 1973.

Mulch Treatments (dilutions) and (rate/ha)	Soil Loss (t/ha) [a] June 19, 1973		Soil Erosion Rating (1 to 10) [b,c] June 19, 1973		July 6, 1973	
	Entire 9m Alone	WF841	Alone	WF841	Alone	WF841
Petroset 468 L (1:50)	7	7	9.3 abc	9.3 abc	6.0 bcdef	7.5 abcd
Straw 3363 to 4484 kg	9	ND	10.0 a	ND	9.0 a	ND
Petroset 1076 L (1:20)	ND	14	ND	10.0 a	ND	8.0 abc
Genaqua 935 L (1:23)	0	20	10.0 a	10.0 a	8.0 abc	7.5 abcd
Polyvinyl Alcohol 1871 L (1:100)	27	18	6.8 cdef	8.0 abc	5.0 defgh	5.5 cdefg
Ecology Control 179 kg (1:14)	20	235	7.5 abcde	5.5 defg	6.5 abcde	4.0 efgh
Wood-fibre 1682 kg	110	ND	6.8 cdef	ND	4.5 efgh	ND
Aquatain 224 kg (1:11)	130	112	5.8 defg	7.5 bcdef	4.0 efgh	4.0 efgh
Check	177	139	5.3 efg	5.0 fg	3.0 fgh	4.5 efgh
Kelgum D 45 kg (1:55)	ND	191	ND	4.8 fg	ND	2.5 gh
Landlock 1122 L (1:20)	220	112	5.0 fg	5.8 defg	3.5 fgh	4.0 efgh
Tinex 1682 kg dry weight	179	ND	5.8 defg	ND	3.5 fgh	ND
Landlock 561 L (1:20)	173	341	5.8 defg	4.0 g	3.5 fgh	2.5 h

Source: Adapted from Green, Woodruff and Blaser (1973:29)

[a] Tonnes of soil loss was estimated by multiplying the number of rills x depth x width x length and assuming 1602 kg of soil per cubic metre of area. This does not include sheet erosion and is a very rough estimate.

[b] Soil erosion ratings were estimated on scale (1 to 10) with 10 being no visible erosion or mulch movement, 8 to 10 = satisfactory to excellent, 5 to 7 = marginal, under 5 = unacceptable.

[c] Numbers within the same column followed by the same letter are not significantly different at the five percent level of probability.

[d] WF 841 = Wood-fibre at 841 kg/ha alone = mulches applied as shown in left column without wood-fibre at 841.

Table 34.22. The effects of soil stabilizers and organic mulches on soil erosion and grass establiishment on a smooth 2:1 cut slope. Rt. 460, Prospect, Virginia, established 21 June, 1973.

Mulch Combinations[a] (Rate/ha)	Erosion Rating (10=Best)[b,c]				Stand[d]	Vegetation Cover (%)		Height (cm)
	June 28	July 6	July 13	Average	July 6	July 13	Aug 1	Aug. 1
Straw 4484 kg + LL 1122 L	10.0 a	10.0	10.0 a	10.0	7 a	62 a	75 a	32 a
Petroset 468 L + WF 841 kg	8.3 ab	9.0	8.3 ab	8.5	7 a	31 bc	46 b	22.9 ab
Genaqua 935 L + WF 841 kg	9.0 ab	8.3	8.0 ab	8.4	5 b	26 bc	46 b	22.4 ab
Petroset 1076 L + WF 841 kg	8.3 ab	8.8	7.3 bc	8.1	7 a	41 b	64 a	25.4 ab
Kelgum D @ 45 kg WF 841 kg	8.3 ab	6.6	6.0 bcd	6.9	3 c	9 cde	34 b	23.9 ab
Ecology Control 179 kg + WF 841 kg	6.8 bc	7.3	4.7 de	6.3	5 b	17 bcde	26 bc	19.8 bcde
Polyvinyl Alcohol 1871 L + WF 841 kg	5.0 cde	6.3	5.0 cde	5.5	5 b	17 bcde	35 b	22.9 bc
Aquatain 112 kg + WF 841 kg	6.5	5.0	5.0 cde	5.5	1 c	3 e	3 d	15.0 cdef
Tinex 1682 kg Dry Weight	6.2 bcd	5.3	3.7 def	5.0	1 c	6 de	11 cd	17.0 cdef
Wood-fibre (WF) 1682 kg	3.8 de	4.0	3.3 ef	3.7	1 c	2 e	6 d	10.4 f
Wood-fibre (WF) 841 kg	3.8 de	4.0	2.7 ef	3.5	1 c	2 e	11 cd	14.5 def
Check	3.8 de	3.2	2.8	3.2	1	3 e	10 cd	17.8 cdef

Source: Adapted from Green, Woodruff and Blaser (1973)

[a] Before mulching the bottom 3.1 m of each plot was treated with a mixture (kg/ha) of Ky 31 fescue 51, weeping lovegrass 11, sericea lespedeza 45, crownvetch 22, and 1121 kg of 10-20-10 fertilizer.

[b] Means within column followed by same letter are not significantly different at the five percent level of probability.

[c] Soil erosion ratings were estimated on scale (1 to 10) with 10 being no visible erosion or mulch movement, 8 to 10 = satisfactory to excellent, 5 to 7 = marginal, under 5 = unacceptable.

[d] Stand ratings are 1 = none, 4 = poor, 6 = fair, 8 = good, 10 = excellent.

Table 34.23. The influence of straw and wood-fibre with 56 and 112 kg/ha of nitrogen and four rates of German millet on erosion control and turf establishment during summer. Rt. 841, Pittsylvania County, Virginia, established 20 July, 1972.[a]

Millet[b] (kg/ha)	Plants/m^2																			
	German Millet				Ky 31 Fescue				Crownvetch				Soil Cover (%)				Erosion Ratings[c]			
	Wood-fibre		Straw		Wood-fibre		Straw		Wood-fibre		Straw		Wood-fibre		Straw		Wood-fibre		Straw	
	N 50	N 100	N 50	N 100	N 50	N 100	N 50	N 100	N 50	N 100	N 50	N 100	N 50	N 100	N 50	N 100	N 50	N 100	N 50	N 100
0	0	0	0	0	35.6	7.6	186.8	219.2	0	0	18.4	35.6	5	5	40	45	0.6	0.5	0.3	0
7	38.9	46.4	60.5	51.8	21.6	24.8	138.2	165.2	0	3.2	28.1	24.8	18	22	22	58	0.5	0.5	0.3	0
13	62.6	73.4	96.1	106.9	32.4	16.2	221.4	199.8	0	0	36.7	18.4	24	28	55	72	0.5	0.4	0	0
20	108.0	103.7	176.0	144.7	29.2	18.4	157.7	126.4	3.2	0	24.8	21.6	26	35	66	74	0.5	0.4	0	0

Source: Adapted from Green, Woodruff and Blaser (1973:33)

[a] Data from one replication: the second and third reps were inadvertantly destroyed during construction.

[b] The area was uniformly seeded with a mixture (kg/ha) of Ky 31 fescue 84.0, redtop 1.7, annual ryegrass 5.6, and crownvetch 16.8. Phosphorous at 224 kg and potassium at 112 kg and 3360 kg/ha of limestone were applied before seeding. Wood-fibre applied at 1680 kg and straw at 4480 kg/ha.

[c] Erosion ratings rank from 1 to 10 with 10 being most severe erosion.

some of the summer tests, other mulches performed as well as or better than straw: wood-fibre at 1680 kg/ha (Table 34.19); Landlock at 67.2 kg/ha and Tinex at 840 kg/ha or 1680 kg/ha (Table 34.19); Genaqua at 112 kg/ha with wood-fibre at 840 kg/ha (Table 34.20); and Genaqua at 112 kg/ha (Table 34.21).

From these studies Green, Woodruff and Blaser found that chemical stabilizers used alone were generally unsatisfactory. Using them with organic mulches, however, made the mulches more persistent and desirable for prolonged stabilization during difficult seeding seasons. Organic materials, such as straw, wood-fibre, wood-bark or wood-chips, were the best for controlling erosion and enhancing turf establishment. Germination with chemical binders alone was generally poor when compared with organic mulches or organic mulch-binder combinations.

They concluded that soil stabilizers are not necessary during the favourable moist and cool season seeding periods (spring season and favourable early fall) except for steep slopes; however, the addition of binders such as Petroset, Aerospray, Landlock, or Curasol will reduce the potential erosion hazards. Organic mulches such as straw, hay or wood-fibre are necessary with conventional smooth grading, but the need for mulches is sharply reduced with stair-step grading or for slopes with roughened, and loose surfaces. For such improved grading methods the rate of organic mulches could be reduced. For seedings made during prolonged winter dormancy periods, straw or wood-fibre organic mulches must be stabilized; asphalt at 2806 to 5612 L/ha was recommended.

34.3 PLAINS REGION

On a south-eastern Montana coal mine, Richardson et al. (1975) and Farmer et al. (1974) studied the effects of topsoiling, irrigation, fertilization, and mulching on the establishment and growth of three grass/legume mixtures (Table 30.3). The reader should consult the two publications for a more detailed description of the methods. The mulch was sphagnum peat moss applied at 5.6 t/ha and held in place by a single layer of jute netting.

Farmer et al. (1974) found significant improvement in seedling emergence due to mulch (Table 34.24). Mulch also significantly increased production of most grass mixtures (Figure 34.2) by the end of the first growing season. The exceptions were the unfertilized native, and native plus introduced irrigated plots.

Richardson et al. (1975) reported on the preliminary plant production results for the second growing season. The effects of the mulch on production were highly variable (Figure 34.3). Production on mulched plots was higher than on unmulched plots for the fertilized irrigated plots (all mixes), and for the fertilized control plots seeded to the introduced, and native plus introduced mixes. Mulch had little or no effect on the unfertilized irrigated plots (all mixes), and the unfertilized control plots (all mixes). The mulch had an apparent depressing effect on all topsoiled plots and the fertilized control plots seeded to the native mix. The authors gave no reasons for the observed changes in mulch effects from the first to the second season.

From these data Richardson et al. (1975) and Farmer et al. (1974) and concluded that topsoiling is essential, but mulches, while adding some benefit in the first year, appear not to be necessary for establishing adequate cover, especially on top-dressed plots.

May et al. (1971) and Jacoby (1968) evaluated the effects of jute and straw mulch on erosion and vegetation establishment on coal spoils near Kemmerer, Wyoming. Three spoil banks of varying ages and pH levels (Table 34.25) were broadcast seeded with a mixture of Agropyron intermedium, A. cristatum, Elymus junceus, and Bromus inermis. After seeding, three mulches were assessed: (1) barley straw alone; (2) 9.1 m by 1.2 m strips of jute mesh netting; and (3) a combination of jute mesh and barley straw.

Jute mesh and barley straw combined were the most efficient in controlling erosion and establishing a vegetative cover (Table 34.26). The individual treatments were quite effective as well. The beneficial effects of the mulch appeared to be greatly reduced by low pH of soil.

Due to the high cost of the jute mesh netting the authors also tested a wire mesh netting with Hordeum straw. The wire net was much

Table 34.24. Effects of mulch on seedling emergence (shoots/m^2), Decker Coal Mine, Montana.

Plot/Treatment	Mulch	No Mulch
Control	68.9[a]	45.9
Topsoiled	65.6	36.1

Source: Adapted from Farmer et al. (1974).
[a] Values are means from all three seed mixes. Emergence in both plots increased from native to native plus introduced to introduced grasses.

Table 34.25. Partial analysis of coal spoil material from three age groups, Kemmerer, Wyoming.

Age (Years)	Texture	pH	Organic Matter %
3	Clay	4.1	5.55
3	Clay	4.5	3.57
9	Sandy Loam	4.8	5.11
9	Clay	7.7	2.27
14	Silt Loam	7.0	3.57
14	Clay	7.4	4.01

Source: Jacoby (1968).

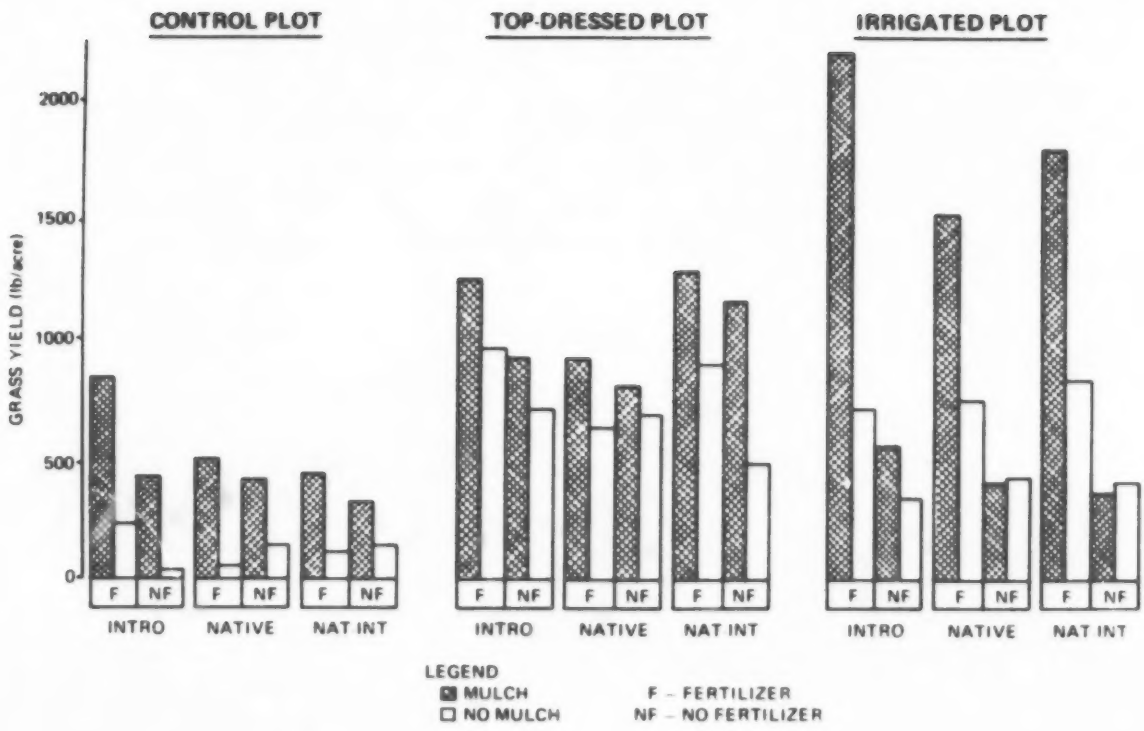

Figure 34.2. Average dry-weight grass production, for each main plot by subplot treatments on a Montana coal spoil. INTRO, NATIVE, and NAT-INT are seed mixtures.

Source: Farmer et.al. (1974)

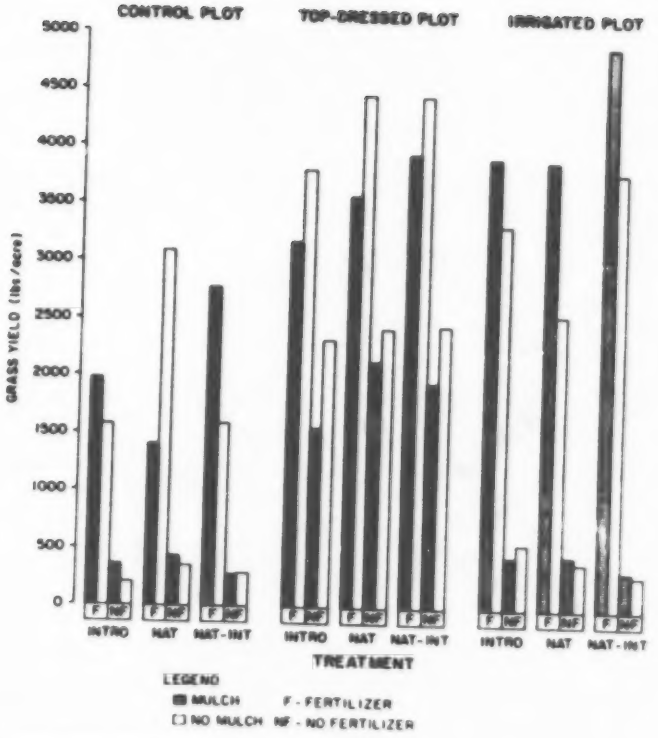

Figure 34.3. Average 1974 dry-weight grass production for each main plot by treatments on a Montana coal spoil. INTRO (introduced), NAT (native), and NAT-INT (native-introduced) are seed mixtures.

Source: Richardson et.al. (1975)

Table 34.26. Average seedling number per square metre for each treatment and age group, and comparative relative density of seedlings for each treatment expressed as a percentage of the highest value in any age group Kemmerer, Wyoming.

Treatment	Age Group							
	15		9 (Irrigation)		9		3	
	No.	%	No.	%	No.	%	No.	%
Jute-Mulch	2754	100.00	1858	64.4	1534	55.7	151	5.5
Mulch	2592	94.1	1134	41.2	1134	41.8	ND	ND
Jute	2387	86.7	1436	52.2	1004	36.5	140	5.1
Fence-Jute-Mulch	1490	54.1	ND	ND	918	32.3	356	12.9
Fence-Jute	1188	43.1	ND	ND	896	32.5	194	7.1
Fence	691	25.1	ND	ND	594	21.6	119	4.3
Control	378	13.7	238	8.6	162	5.9	11	0.4

Source: Adapted from Jacoby (1968).
[a] ND = No data.

easier to handle than the jute mesh. May et al. (1971) and Jacoby (1968) found that the mesh and straw treatment provided a good vegetation cover while areas not treated had no cover even though seeded at similar rates.

Meyer, Johnson and Foster (1972) examined the erosion control potential of several mulches on construction sites in Indiana. The test site was a side-slope of a borrow pit composed of compacted calcareous till underlying a silt loam soil. The study area was shaped to a uniform 20% slope with a northerly exposure. The soil surface was firmed with a bulldozer then smoothed with a tiller rake.

The following mulch treatments were studied:

1. No mulch.
2. Straw mulch. Triticum straw from a chopper-blower was applied uniformly to the soil surface at a rate of 5.2 t/ha.
3. Crushed stone. Crushed limestone was studied at five rates: 33.6, 134.5, 302.7, 538.1, and 840.8 t/ha. The material designated as No. 4 road mix ranged from 0.6 to 3.8 cm in diameter with about half larger than 1.9 cm.
4. Gravel. Washed road gravel with a size distribution similar to the crushed stone was studied at a rate of 157.0 t/ha.
5. Wood chips. This mulch consisted of chipped small trees and tree limbs which is becoming a common waste material when trees and shrubs are cleared from construction sites. The wood chips were of mixed hardwoods, chipped while in leaf. Most of the leafy material deteriorated during the month the chips were stockpiled before spreading. Rates of about 4.5, 9.0, 15.7, 27.0, and 56.1 t/ha were tested.
6. Portland cement. Recent research has shown that Portland cement applied to the soil surface can greatly reduce

soil erosion on slopes of moderate steepness and length. A spray application of about 4.5 t/ha was studied to test its merits on steep, denuded slopes.

Following controlled erosion tests, plots were seeded in September with 13.6 kg each of Lolium perenne and Festuca sp., and fertilized. Grass cover was adequate (more than 75% cover) on plots mulched with 303 and 538 t/ha stone, 27 t/ha wood chips, and 157 t/ha gravel and straw. Plots without mulch and those mulched with cement and 34 t/ha stone had less than 25% cover.

Meyer, Johnson and Foster (1972) were more interested in the erosion controlling capabilities of the mulches rather than their ability to provide a vegetative cover for erosion control. In fact, they suggested using a heavy application of stone or gravel without a vegetative cover for areas that are extremely susceptible to erosion.

Stripnieks and McKenna (1974) attempted to find the most suitable mix of Conwed wood-fibre and Curasol AH for mulching and vegetation establishment along roadsides in Ontario.

During the fourth week of July 1973, 0.4 ha plots were laid out for each combination. Each of these was replicated four times to provide a diversity in soil, moisture, and slope conditions. The soil in the test plots had a loose, granular, sandy sub-base with a light application of scarified top soil, 5 cm in depth.

A total of five mulch combinations were tested on a seeding mix of 34 kg standard M.T.C. grass mixture, 2.3 kg Trifolium repens cv. White Dutch, 4.5 kg Lotus corniculatus, 226.8 kg of 5-20-2 fertilizer, 34 dm^3 Secale cereale as a nurse crop, and 0.9 L of legume inoculant. The five month combinations were: 635 kg of Conwed for test plots A to D, inclusive, 453 kg of Conwed for plot E and 136, 91, 46, 0 and 91 L of Curasol AH for plots A to E, respectively.

They made observations on all plots six weeks after completion of seeding and mulching. Rainfall during this period was low until two weeks prior to evaluation. In general, the authors concluded that the optimum combination would be 225 L/ha of Curasol AH with 1568 kg/ha Conwed fibre. Hydromulches of Curasol AH and Conwed fibre were

expensive to apply and required a great deal of water when compared to straw mulching but they may be extremely effective along highway shoulders where high-speed traffic tends to blow conventional straw mulch off seeded areas. In addition, seed germination in the hydromulched plots appeared to be somewhat better than in adjacent straw mulched plots.

34.4 OTHER GEOGRAPHIC REGIONS

In Kentucky, Vogel (1975) tested the effects of liming, fertilization and mulch on the establishment of a grass/legume mix on acid coal spoils. The Clay County spoil had the following characteristics: pH = 2.3; exchangeable acidity = 13.7 to 24.1 meq/100 g spoil; specific conductance = 3.7 mmhos/cm; and black acid shale with sandstone. The River Gem spoils had the following characteristics: pH = 3.0; exchangeable acidity = 8.3 to 9.4 meq/100 g spoil; specific conductance = 2.1 mmhos/cm; and acid sandstone with shale.

The six treatments are shown in Table 34.27. Plots were limed, rototilled to between 5 and 10 cm for seed-bed preparation, and fertilized. Shredded bark (Pinus sp.) was applied as a mulch at a rate of 189 m^3/ha, three days after seeding. Plots were seeded with a grass/legume mix (Table 34.28) in May and cover values were taken for four years.

In the Clay County spoils no vegetation established unless lime was applied. On the less acid River Gem spoils, only the fertilized and mulched plots established a vegetation cover when spoils were not limed. On both spoils, the limed, fertilized, and mulched plots had the greatest cover (Table 34.27). On both sites mulch on the unlimed plots was partially disintegrated by acid, whereas most of the bark was still present on the limed plots.

Vogel concluded that all three treatments must be applied to obtain a suitable cover on acid spoils. The mulch obviously enhanced the other treatments.

Table 34.27. Percentage of ground surface covered with vegetation on acid Kentucky spoils treated with lime, fertilizer, and mulch, 1972 to 1975.

Treatment	Clay County spoils[a]				River Gem Spoils[b]			
	72 8 21	73 4 26	74 6 11	75 6 2	72 8 11	73 5 30	74 6 4	75 5 30
1. None (control)	0	0	0	0	0	0	T[c]	T
2. Fertilizer	0	0	0	0	0	0	T	T
3. Fertilizer + mulch	0	0	0	0	15	35	40	50
4. Lime	5	10	5	3	20	10	30	35
5. Lime + fertilizer	15	20	15	10	35	50	65	75
6. Lime + fertilizer + mulch	55	70	65	65	65	85	95	100

Source: Adapted from Vogel (1975).

a Plots established 05 May 1972. Cover values are mean of two replications.

b Plots established 18 May 1972. Cover values are mean of three replications.

c Trace of vegetation (three percent cover).

Table 34.28. Species and seeding rates for grass/legume mix, Clay County and River Gem plots, Kentucky.

Species	Seeding rate (kg/ha)
Weeping lovegrass	4.5
Grain sorghum	11.2
Ky-31 tall fescue	16.8
Sericea lespedeza	13.5
Birdsfoot trefoil	6.7
Kobe lespedeza	9.0

Source: Adapted from Vogel (1975).

Table 34.29. Percentage of ground cover on Clay County plots established in 1975[a] (mean of three replicates).

Mulch treatment	Tillage	Lime rate (t/ha)		
		67	101	135
No mulch	Shallow	20	20	30
	Deep	10	15	15
Mulch	Shallow	85	80	80
	Deep	70	75	65

Source: Adapted from Vogel (1979).
[a] Plots established 29 March 1975; cover evaluated 04 June 1975.

In a second study on the Clay County spoils, Vogel (1975), examined the effects of three liming rates, two tilling depths, and mulch on vegetation establishment. A mixture of Secale cereale cv. Balbo, Eragrostis curvula, Festuca arundinacea cv. Ky-31, Lotus corniculatus, Lespedeza cuneata, and Lespedeza sp. cv. Kobe was sown on all plots, and fertilizer was applied. One half of all treatments was mulched with shredded hardwood bark at 142 m^3/ha; one half was not mulched. The liming, tillage, seeding, fertilizing, and mulching were all done on one day.

Two months after planting, the vegetative cover was much higher (Table 34.29) and seedlings were much larger on the mulched plots than on the unmulched plots. The author noted that the mulch was beneficial mainly because it retained moisture in the soil even during rainless periods in the summer. From the results of these two experiments Vogel felt that an application of bark mulch at 113 to 189 m^3/ha would be most beneficial for amending extremely acid coal spoils.

Barnhisel, Powell and Akin (1975) studied the effects of site preparation, mulching, and phosphorus fertilization on the establishment and maintenance of Trifolium pratense and Festuca arundinacea cv. Ky-31 seeded on Kentucky coal spoils comprised of gray, weakly cemented shale and siltstone having a near neutral pH and containing little or no sulfide minerals (low potential acidity). Chemical tests indicated that these spoils were very low in plant-available phosphorus and nitrogen, but contained adequate amounts of potassium, calcium, and magnesium.

The four tillage treatments were performed on the contour, with the size of the plots being 6.1 x 20.1 m. The site was smooth graded, disced, ripped, and mulched. The ripper consisted of two spikes mounted on the tool bar of a D-9 Caterpillar tractor, operated at a depth of 60 cm. The tractor made two passes per plot so that the ripped channels were spaced approximately 1.6 m apart.

A Fescue hay mulch was applied at 1600 kg/ha. Plots were fertilized with nitrogen and three rates of super phosphate. The seeding rate for F. arundinacea and T. pratense was 44.8 and 13.4 kg/ha, respectively. Forage data for three years were obtained for each plot.

The addition of the mulch improved first season yields in all plots but had the greatest effect in the unfertilized plots (Table 34.30). Mulch improved yields in all plots in the second season but the beneficial effects of the mulch had diminished by the third growing season. The authors attributed the improved yields on mulched plots to improved moisture conditions in these plots.

Emanual (1976) compared three types of hardwood bark mulches with wood and paper fibres for establishing vegetation on regraded coal spoils in West Virginia.

Bark fines result from screening shredded hardwood bark to produce decorative bark mulches. The two bark-fibre products were produced from raw bark from a sawmill debarker: (1) bark fibre A--raw bark was hammermilled and processed through a pressurized refining system; and (2) bark fibre B--raw bark was hammermilled and processed through an attrition mill. Except for colour, both bark-fibre products were physically similar to wood fibre hydromulch.

In the spring of 1973, eighteen 0.02 ha plots were established on a regraded strip mine. All plots had a south-easterly aspect and the same slope. Five mulch treatments were used: (1) bark fines, (2) bark fibre A, (3) bark fibre B, (4) wood-fibre, (5) and paper fibre. All mulches were applied at a rate equivalent to 1680 kg/ha at 20 percent moisture content. The treatments were replicated twice and applied randomly to the test plots. Three plots were left unmulched for controls.

All plots were fertilized and seeded with 16.8 kg of Festuca arundinacea, 6.7 kg of Agrostis alba, 3.4 kg of Eragrostis curvula, 14.6 kg of Lolium perenne, 22.4 kg of Lespedeza cuneata, and 11.2 kg of Echinchloa frumentacea per hectare. Fertilizer, seed, and mulch were applied with a hydroseeder.

Percent cover data were taken two months after seeding, at the end of the growing season, and 14 months after seeding. Two months after seeding, the plots mulched with hardwood bark and paper fibre had significantly more vegetation than plots mulched with wood-fibre and the control plots (Table 34.31). There were no significant differences in cover among the three bark fibres tested. By the end of the first

Table 34.30. Effect of site preparation and phosphorus treatments on oven-dried forage yield (kg/ha), 1973, 1974, and 1975 from Kentucky coal spoils.

Treatment	Phosphorus Applied in 1972 (kg/ha)		
	0	84	168
1973 (two cuttings)			
Disked 1x	315	2089	2764
Disked 3x	113	1469	2035
Disked 3x, ripped	423	2638	3508
Disked 3x, ripped, mulch	1232	2966	3880
1974 (two cuttings)			
Disked 1x	782	1142	1142
Disked 3x	525	798	887
Disked 3x, ripped	788	1005	1257
Disked 3x, ripped, mulch	1014	1679	1765
1975 (one cutting)			
Disked 1x	1210	1303	1406
Disked 3x	913	1246	1271
Disked 3x, ripped	1280	1023	1169
Disked 3x, ripped, mulch	1196	1313	1196

Source: Barnhisel, Powell and Akin (1975).

Table 34.31. Percent cover of plants growing on mulched coal spoil in West Virginia.

Treatment	Vegetative coverage[a]		
	27 June 1973	26 October 1973	13 June 1974
Control	63 b	75 a	87 a
Wood-fibre	58 b	83 a	92 a
Paper fibre	83 a	88 a	92 a
Hardwood bark fines	86 a	93 a	95 a
Hardwood bark fiber A	76 ab	89 a	89 a
Hardwood bark fiber B	67 ab	85 a	88 a

Source: Adapted from Emanual (1976).
[a] Any two means with different letters are significantly different at the 5 percent level.

growing season there were no differences in cover among treatments and all plots had adequate vegetative cover.

Emanual noted that both bark fines and bark fibres are as effective as commercial hydromulches for establishing vegetation on disturbed soils and that both can be applied by hydroseeders. The bark fines are cheapest as they are a byproduct of hammermilling and require only screening before use.

Sarles and Emanual (1977) also examined the use of bark as a mulch in four locations in West Virginia. Table 34.32 provides details of the four test sites while Table 34.33 shows the lime, seed, fertilizer, and mulch treatments at each site.

The White Oak Mountain coal mine site was seeded and mulched in late October. An early winter and heavy erosion losses contributed to the poor vegetation establishment on the plots. By June, only the 7.3 t bark treatment produced significantly better cover than the unmulched control plots (Table 34.34). The 7.3 t bark treatment and the straw mulch produced significantly taller grass plants. By the fall, only the 5.4 t bark mulch had significantly better cover than the control, followed by the 7.3 t bark treatment and the straw mulch. There were no significant differences in plant height by the fall season.

Plots at the Monson surface mine were seeded and mulched in early fall and by November 1970 the two mulch treatments had resulted in stands of grass with 83% cover (Table 34.35). Stand density was significantly higher on mulched plots than on control plots and plants growing in the straw mulched plots were taller than plants in other plots (Table 34.35). By July 1971 stands under the straw mulch were denser and exhibited greater vigour; heights were similar.

Two roadside sites (Lewisburg and Mullens) were seeded and mulched in spring. On the north-facing slopes at Lewisburg, vegetative cover on bark mulched plots was significantly higher than on the wood-fibre plots eight weeks after seeding (35.36). By fall there were no differences in cover among treatments; however, plant density was greater on the wood-fibre plots. On south-facing slopes, only 36.7 m^3

Table 34.32. Description of the seeding and mulching test sites in southern West Virginia.

Location	Kind of Site	Elevation (m)	Exposure	Slope (%)	Soils
White Oak Mountain Raleigh County	Coal surface mine	914	North	4 to 21	Yellow shaley clay; pH 5.1
Lewisburg Greenbrier County	Highway fill-slope	640	North and south	50	Coarse calcareous shale with some clay; pH 7.6; Pond K medium to high.
Mullens Wyoming County	Highway cut-slope	396	North	50	Rocky soil from sandstone parent material; pH 5.7. P low; K medium.
Monson McDowell County	Coal surface mine	732	West	0 to 4	Highly variable mixture of sand, rock[illegible]

Source: Adapted from Sarles and Emanuel (1977:210)

Table 34.33. Lime, seed, and fertilizer applications and mulch treatments on four disturbed sites in southern West Virginia.

Location	Plot Size (ha)	Lime, Seed and Fertilizer per hectare	Mulch Treatments per hectare	Replications
White Oak Mountain Raleigh County	0.04 (1/10 acre)	224 kg ammonium nitrate 112 kg triple superphosphate 11.2 kg perennial ryegrass *Lolium perenne* 16.8 kg Kentucky 31 fescue, *Festuca arundinacea* 11.2 kg sericea lespedeza, *Lespedeza cuneata* (applied with cyclone seeder)	3.4 t straw 2.24 t bark residue 4.5 t bark residue 8.9 t bark residue 13.5 t bark residue 17.9 t bark residue No mulch	3
Lewisburg Greenbrier County	0.04	2.24 t ground limestone 448 kg 10-20-10 mixed fertilizer 100.9 kg urea (46% N) 15.7 kg perennial ryegrass 45 kg Kentucky 31 fescue 47.1 kg sericea lespedeza (applied with a hydroseeder)	30m^3 bark residue 60m^3 bark residue 90.7m^3 bark residue 1177 kg wood-fibre	6
Mullens Wyoming County	0.02 (1/20 acre)	2.24 t ground limestone 897 kg 10-10-10 mixed fertilizer 202 kg urea (47% N) 15.7 kg perennial ryegrass 45 kg Kentucky 31 fescue 40.4 kg sericea lespedeza (applied with a hydroseeder)	30m^3 bark residue 60m^3 bark residue 90.7m^3 bark residue 1177 kg wood-fibre	4
Monson McDowell County	0.02	56 kg ammonium nitrate 112. kg perennial ryegrass 8.4 kg Kentucky 31 fescue 11.2 kg sericea lespedeza 5.6 kg weeping lovegrass, *Eragrostis curvula* (applied with a hydroseeder)	47m^3 shredded bark 4.5 t straw/asphalt No mulch	2

Source: Adapted from Sarles and Emanuel (1977:210)

Table 34.34. Effect of mulch treatments on the percent, density, and height of grass-legume cover seeded October 1969 on the White Oak Mountain surface-mine site, West Virginia.

Mulch treatment per hectare	Vegetative Cover (%)		Plant Density (index)		Plant Height (cm)		
					Grass		Sericea Lespedeza
	June 1970	October 1970	June 1970	October 1970	June 1970	October 1970	October 1970
3.4 t straw	38ba	45ba	90b	125b	14.7a	15.8b	8.6b
2.2 t bark	28ba	33ba	55b	93b	12.2ac	14.2b	8.1b
4.5 t bark	20ba	20a	58b	72b	8.9ac	12.7b	6.9b
9.0 t bark	18ba	21a	50b	71b	10.2bac	11.7b	8.4b
13.5 t bark	39ba	61b	80b	132b	13.5bac	14.5b	9.7b
18.0 t bark	47b	56ba	58b	126b	15.2b	13.7b	12.2b
No mulch	10a	24ba	41b	70b	8.4c	14.2b	9.1b
			n.s.	n.s.		n.s.	n.s.

Source: Adapted from Sarles and Emanuel (1977:211)

Note: Treatment means followed by the same letter within each column are not significantly different at the 5 percent level; n.s. appears at the bottom of columns where none of the means are significantly different.

Table 34.35. Effect of mulch treatments on the development of grass-legume vegetation seeded September 1960 on the Monson, West Virginia, surface-mine site.

Mulch treatment per hectare	Vegetative Cover (%)		Stand Density (index)		Stand Vigour (index)		Plant Height (cm)	
	November 1970	July 1971	November 1970	July 1971	November 1970	July 1971	November 1970	July 1971
4.5 t straw/asphalt	83b	98b	83b	79b	83b	69b	19.1b	40.6b
47.2 m^3 bark	83b	91b	71b	54ba	58b	46ba	8.26a	35.6b
No mulch	50b	81b	46a	37a	67b	37a	6.05a	38.1b
	n.s.	n.s.			n.s.			n.s.

Source: Adapted from Sarles and Emanuel (1977:211)

Note: Based on rating scores: dense or vigourous = 100 to 67; moderate or vigour = 66 to 34; sparse or weak = 33 to zero.
Treatment means followed by the same letter within each column are not significantly different at the 5 percent level; n.s. appears at the bottom of columns where none of the means are significantly different.

Table 34.36. Development of spring-seeded grass-legume vegetation on a highway fill (2:1 slope) at Lewisburg, West Virginia, as affected by slope exposure and mulch treatments.

Mulch treatment per hectare	June 1970	November 1970	July 1971	June 1972	Density of Grass: Plants (index) November 1970	Height of Grass: Plants (cm) November 1970
North-facing slope:						
1177 kg wood-fibre	5.0a	74.3b	78.0b	65.0b	150a	14.0b
30.2 m^3 bark	53.3b	84.7b	89.3b	70.0b	242b	16.0b
60.5 m^3 bark	58.3b	86.0b	92.0b	66.7b	242b	15.5b
90.7 m^3 bark	61.0b	89.0b	86.3b	63.3b	253b	14.2b
		n.s.	n.s.	n.s.		n.s.
South-facing slope:						
1177 kg wood-fibre	5.0a	16.0a	31.7b	30.0b	47a	9.9c
30.2 m^3 bark	6.7a	51.7b	54.7b	50.0b	113b	10.9ac
60.5 m^3 bark	9.3ba	44.3ba	56.0b	41.7b	114b	12.7ba
90.7 m^3 bark	18.3b	53.3b	62.0b	36.7b	141b	13.5b
			n.s.	n.s.		

Source: Adapted from Sarles and Emanuel (1977:212)

Note: Treatment means followed by the same letter within each column are not significantly different at the 5 percent level; n.s. appears at the bottom of columns where none of the means are significantly different.

of bark provided greater initial cover (Table 34.36). By spring of next year there were no differences in cover among treatments.

At the Mullens site, cover was significantly higher eight weeks after seeding on the plots mulched with 12.2 m^3 of bark; however, no cover differences were found by the fall (Table 34.37). Density of grasses was greater on bark mulched plots by the fall of the first growing season.

From these studies Sarles and Emanual (1977) concluded that bark mulches enhanced seed germination and development of plant cover on disturbed sites. They recommended the use of 56.7 m^3/ha of bark mulch on north and east facing slopes that are 2:1 or less. For slopes greater than 2:1, south or west facing slopes, and for overwinter protection of sites they recommended 94.5 m^3/ha.

Plass (1973) presented qualitative data from two studies which assessed the effectiveness of several mulches and soil stabilizers for erosion control and vegetative establishment on coal spoils in West Virginia. In general, soil stabilizers applied to the spoils without an added mulch did not improve plant germination whereas stabilizers applied with mulch had better vegetative cover and less sediment loss. Mulches alone provided more cover than either of the above.

Michelutti (1974) described two experiments which compared plant establishment on acid nickle mine tailings and on tailings amended with a straw-asphalt mulch. In the first experiment, the growth of legumes in pots with sand (control) and mulch, tailings without mulch, and tailings with mulch were tested. The plants in the mulched pots exhibited better growth than the unmulched pots (Figure 34.4). In the second test, 16 species of grasses and legumes were field grown in plots with straw-asphalt, Curasol or 5 cm soil mulches. The mulch covers all proved to be superior to unmulched plots, with the topsoil plots doing best of all.

Schuman et al. (1980) compared standing stubble and crimped straw as mulches for establishing a grass cover on a regraded uranium spoil dump near Shirley Basin, Wyoming. The spoil material is a predominantly tan, medium-to-coarse grained, arkosic sandstone and

Table 34.37. Development of spring-seeded grass-legume vegetation on a highway cut (2:1 slope) at Mullens, West Virginia, as affected by mulch treatments.

Mulch treatment per hectare	Vegetative Cover (%)				Density and Height of Plants October 1970		
	June 1970	October 1970	July 1971	June 1972	Grass (index)	Grass (cm)	Sericea Lespedeza (cm)
117 kg wood-fibre	79a	92b	95b	95b	201a	13.7b	8.1a
30.2 m^3 bark	99b	97b	100b	100b	231b	21.8b	14.5b
60.5 m^3 bark	95ba	97b	100b	100b	227b	22.6b	16.3b
90.7 m^3 bark	94ba	96b	100b	100b	234b	16.8b	13.5b
		n.s.	n.s.	n.s.		n.s.	

Source: Adapted from Sarles and Emanuel (1977:212)

Note: Treatment means followed by the same letter within each column are not significantly different at the 5 percent level; n.s. appears at the bottom of columns where none of the means are significantly different.

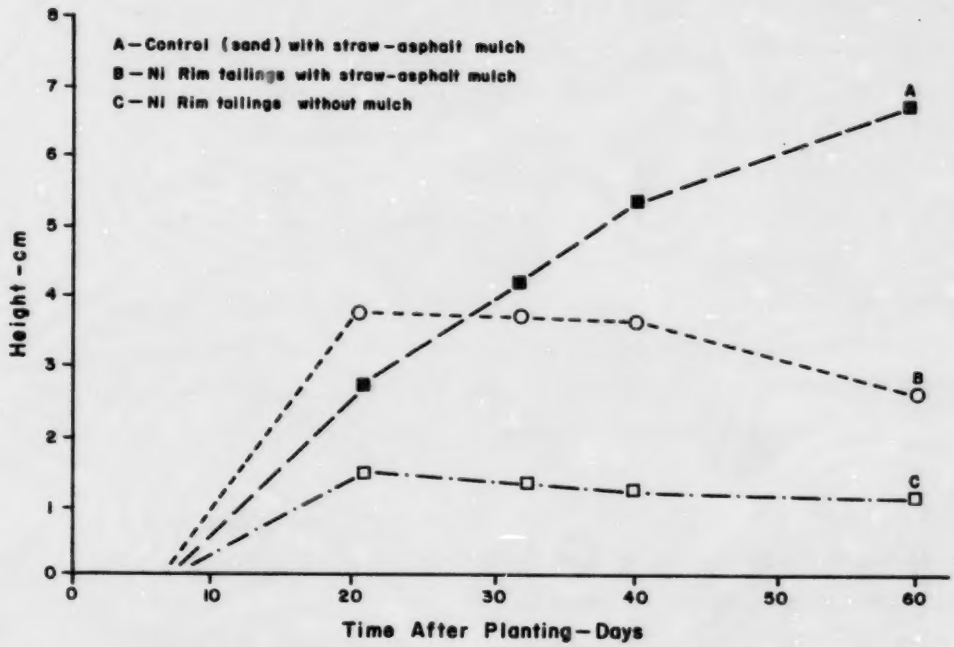

Figure 34.4. Effect of a straw-asphalt mulch on growth of legumes in pots containing acid nickle tailings from the Sudbury area.

Source: Michelutti (1974)

siltstone. The topsoil is a fine loam material. The pH and electrical conductivity of the topsoil saturation paste were 7.1 and 2.2 mmhos/cm, respectively. The seed-bed was chiselled, disced, harrowed, and fertilized. Twenty plots were established, each 5 by 45.7 m. Ten plots were drill seeded in May with 50 kg/ha of Hordeum vulgare cv. Otis. The other 10 plots were left fallow with weeds controlled. Hordeum straw was harvested in September.

In October, all Hordeum stubble plots and fallow plots were drill seeded with a mixture of Agropyron dasystachyum cv. Critana, Stipa viridula, A. trachycaulum and A. smithii cv. Rosana at a rate of 15.5 kg/ha of pure live seed. Each species comprised 25 percent (by seed numbers) of the mixture. Hordeum straw was hand scattered on the seeded fallow plots at the rate of 5 t/ha, then crimped in two directions with a cutaway rolling disc.

Grass establishment was assessed the following July by the line transect method. The crimped straw mulch resulted in an average of 48.6 seedlings per 3 m transect, while the stubble treatment resulted in an average of 54 seedlings per 3 m transect. The difference was not significant.

The authors found that stubble was a more desirable mulch however, as it significantly increased infiltration and cost much less to apply than the crimped straw mulch.

Leiser et al. (1974) compared a total of 15 erosion control or seeding additive chemicals in replicated tests at Ward Valley, Luther Pass (and on Kingsbury Grade as part of the Federal Bureau of Roads project), California. None was superior to wood-fibre at 1120 kg/ha applied with seed and fertilizer. The plastics sometimes reduced plant establishment. A review of these experiments in June 1974 showed differences only at Ward Valley, which are presented in Table 34.38. Grass stands were rated on a 1 to 10 basis (1 = no establishment, 10 = excellent). The treatment without fertilizer was uniformly poor. Seed and fertilizer alone equalled or exceeded all treatments except 1120 kg/ha of wood-fibre. There did not appear to be differences at the other sites. All treatments were effective on the benches at Kingsbury

Table 34.38. Effect of erosion control chemicals on grass establishment at Ward Valley, California. Seeded October, 1971, evaluated June, 1974.

Treatment	Rate	Grass Stand[a]
Control A	Seed alone, no fertilizer, no cover	4
Control B	Seed + fertilizer only, no cover	7
Wood Fibre	1120 kg/ha, 28 148 L/ha water	8
Terra-Krete	1689 L/ha, (6% in 28 148 L/ha water)	5
Verdyol Super	89.0 kg/ha + wood fibre 1120 kg/ha and 28 148 L/ha water	6
Ecology Control	89.6 kg/ha + wood fibre 1120 kg/ha and 28 148 L/ha water	6
Soil Seal	818 L/ha + wood fibre 1120 kg/ha and 56 296 L/ha water	4
Curasol AE	90 gal/acre + wood fibre 840 kg/ha and 28 148 L/ha water	5
Terra Tack I	22.4 kg/ha + ground barley straw 1120 kg/ha and 28 148 L/ha water	7
Terra Tack I	33.6 kg/ha in 9382 L/ha water applied over whole straw at 2240 kg/ha	6
Terra Tack I	33.6 kg/ha in 14 074 L/ha water	5
Aquatain	1215 L/ha in 9382 L/ha water	6
Earth-Pac	8 mL/m^2 in 28 148 L/ha water	6
SSO	94 L/ha	
Excelsior Erosion Control Blanket		5 7

Source: Adapted from Leiser et al. (1974).
[a] 10 = excellent, 1 = none.

while none were effective at Luther Pass probably because of frost heaving.

In a second experiment, Leiser et al. (1974) compared Excelsior mats, wood-fibre, and two thicknesses of woven paper at two sites (Luther Pass and Chamberland) in California. An average of the results at the two sites in July 1973 (Table 34.39) showed no treatment differences. An evaluation in June 1974 showed hydroseeding to be superior to Excelsior at Chamberland (in two of three replications) and inferior at Luther Pass (in two of three replications), indicating that mulch treatment results may vary depending on site (soils, physiography, climate) conditions. Excelsior was only slightly better than the single paper mat. Doubling the mat did not improve the results but may have reduced grass establishment.

Barnett, Diseker and Richardson (1967) examined six mulching techniques for establishing grasses on state highways in Georgia. Plots were set out in three Georgia counties. Soils were classed as sandy clay loam for the Oconee and Peach County sites and clay at the Wilkes County site. Soils were primarily exposed B and C horizons.

Each site was graded to 2.5:1 slope and then fertilized and limed. This was followed by rototilling to a depth of 2.5 to 15.2 cm. After tillage, seeds were broadcast as follows: on the Oconee and Peach County sites, which were seeded in the fall, 2.2 kg of Festuca arundinacea, 22.4 kg of Paspalum notatum var. saurae, and 3.4 kg of Vicia cracca per hectare; on the Wilkes County site, which was seeded in the spring, 11.2 kg of Cynodon dactylon, 22.4 kg of P. notatum, and 3.4 kg of V. cracca per hectare were used. After seeding, all plots were firmed with a cultipacker.

Mulch treatments were chosen to evaluate several mulching methods currently being used by different highway departments and to provide a range of surface cover from none to complete. Grain straw mulch at the rate of 4.5 t/ha was used for all mulch treatments. The treatments were:

1. Bare, no mulch.
2. Surface-applied mulch treated in place with 757 to 946 L

Table 34.39. Effect of erosion control mats on grass stand at two California locations[a]. Installed fall 1972, rated July 1973 on a 1 to 10 basis[b].

Treatment	Luther Pass	Chamberland	Mean
Hydroseeding + wood fibre, 1122 kg/ha	5	9	7
Hydroseeding + excelsior blanket	7	7	7
Hydroseeding + single paper mat	6	6	6
Hydroseeding + double paper mat	6	4	5

Source: Adapted from Leiser et al. (1974).

[a] Luther Pass, 03-ED-89 P.M. 4.37-4.45 and Chamberland, 03-PLA-89 P.M. 1.27-1.42.

[b] Rating scale: 10 = excellent, 1 = none.

AE-5 asphalt at a rate of 835 to 1043 L/t of straw.

3. Mulch mixed in the previously tilled soil surface with a rotovator, then seeded and cultipacked.
4. Simulated Florida method or "whisker dams" in which straw mulch is embedded or pressed into the prepared soil, using a 0.09 m diameter weighted roller equipped with blunt coulters spaced 20.3 to 30.5 cm apart, roller operated on the contour.
5. Simulated California method, which is similar to Treatment 4 except the coulters are replaced with blunt stubs that are staggered along alternate rows. (These stubs punch the mulch into the prepared soil about 30.5 cm apart in a checkered pattern).
6. Mulch mixed into the prepared soil surface with a rotovator, then seeded and cultipacked followed by an application of AE-5 asphalt at the rate of 835 to 1043 L/t of straw. Hot asphalt from a truck was applied with a standard patch nozzle. Precision was limited due to the hand application technique used and to the fact that no precise method was available for controlling the application rate on small plots.
7. Standard Cartersville method: surface-applied mulch after planting and cultipacking.

Plots were exposed to a test storm equal to a one-year frequency storm (3.3 cm in 30 min) and to a 10-year frequency storm (6.9 cm in 60 min) to assess the erosion controlling properties of the various mulches.

Stand and cover were evaluated in March and November. Stand reflects the success of the various mulch treatments in keeping seeds in place and providing the proper protection and moisture conditions during the early stages of growth. Cover is indicative of durability of the mulch as influenced by treatment as well as the cover provided by the plants themselves. The evaluations made in March ranked surface mulch (Treatment 7) highest in both stand and cover, and no mulch

(Treatment 1) lowest (Table 34.40). Treatments 4, 3, and 2, grouped together, were second highest in stand and cover, followed by Treatments 5 and 6. The poor stand and cover on the bare plots reflected the severe erosion from unprotected slopes. The cover evaluations made in November showed satisfactory stands had been established on all mulch treatments. Barnett, Diseker and Richardson (1967) noted that Treatments 4 and 7 provided the best erosion control but that Treatment 7 was easier to apply.

Haynsworth (1971) has reported on the use of mulches in early reclamation trials on kaolin mining wastes in Georgia. Spoils were row seeded with 29 species native to the region; the site was limed and fertilized. One half of the site was then mulched with 4480 kg/ha of Pinus sp. straw. The quickest germination and overall best stand was found on the mulched portion of the site. Species germinated on the unmulched portion but most of the plants lacked vigour and the stand deteriorated through the summer.

Bradshaw et al. (1975) examined the effects of five mulch/stabilizer treatments on the establishment of Lolium perenne and Trifolium repens on china clay wastes in Cornwall, England. The two species were hydroseeded onto an artificial sand slope and the five treatments applied. Erosion, loss of seeds, and establishment of seedlings were monitored at weekly intervals.

The results (Figure 34.5) show that establishment was assisted by a mulch such as mica or peat, but was considerably reduced by a latex or organic stabilizer. The stabilizers were not sufficiently effective in binding the coarse sand and so allowed erosion. Furthermore, the latex coated the surface sand particles breaking capillary rise thus reducing germination by imposing a water deficient microclimate at the soil surface. The authors noted that the mulch-stabilizer combination was no more successful than the mulch alone, yet cost considerably more.

34.5 SUMMARY

A mulch is defined as "any non-living material placed or left on or near the soil surface for the purpose of protecting it from

Table 34.40. Stand and cover evaluations (in percent) of six mulching treatments used on Georgia highways.

Treatment No.	March 2 to 3, 1965[a]				November 1 to 2, 1965			
	Oconee		Peach		Oconee	Peach	Wilkes(1)	Wilkes(2)
	St.	Cov.	St.	Cov.	Cov.[b]	Cov.[b]	Cov.[c]	Cov.[c]
1 Bare	48	10	30	4	30	25	40	75
1 Bare	7	1	18	3	10	50	90	40
5 California	37	15	77	22	40	98	95	45
2 Mulch + asphalt	92	27	63	18	90	95	80	90
6 Mulch mixed + asphalt	28	4	65	27	80	95	85	90
3 Mulch mixed	77	23	75	20	80	75	95	95
7 Mulch (Cartersville)	87	25	88	37	95	100	95	50[d]
4 Whisker dams (Florida)	67	27	75	20	70	80	100	90

Source: Adapted from Barnett, Diseker and Richardson (1967), Agronomy Journal, Volume 59, 1967, pages 83-85 by permission of the American Society of Agronomy.

[a] All values in percent.

[b] Mostly fescue, some crownvetch, treatments 2 and 4

[c] Mostly common bermudagrass with some bahiagrass on all plots

[d] Unexplained bare area on upper half of this plot

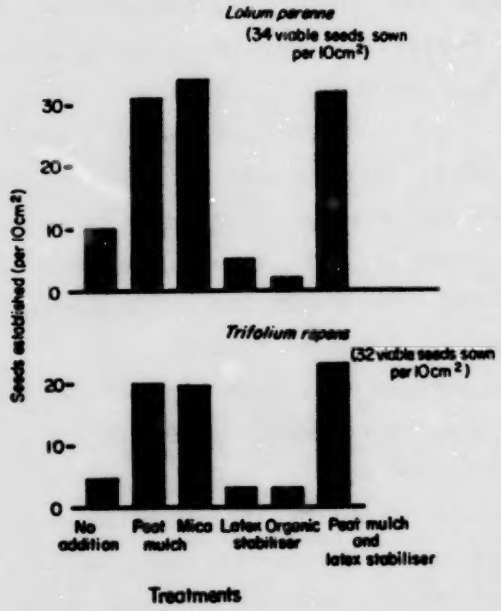

Figure 34.5. The effect of various mulches and stabilizers on establishment of Lolium perenne and Trifolium repens. Seed was broadcast on an artificial China clay waste slope then covered with the mulch.

Source: Bradshaw et al. (1975)

erosion or protecting plants from heat, cold, or drought" (USDA, Forest Service 1979). Common mulches are organic fibres (straw, wood-fibres, wood chips, hay, bark), fabrics or mats, rock, and soil.

Mulches provide the following advantages in that they may: (1) prevent erosion (wind and water); (2) conserve moisture; (3) prevent physical damage; (4) increase infiltration; (5) improve microclimate; (6) add seeds or reduce invasion of unwanted species; and (7) supply nutrients and add micro-organisms. Mulches also have disadvantages in that they may: (1) be expensive; (2) cause nitrogen deficiencies (and possibly phosphorus and sulphur deficiency); (3) increase soil temperatures thereby causing premature germination; (4) lower temperatures and reduce or slow germination; (5) attract unwanted organisms (plant and animal); and (6) require skilled equipment operators for application. The advantages and disadvantages of several common mulches are listed in Table 34.1.

No studies of mulches have been carried out in the Oil Sands region. Results from studies on sandy sites (in rather far-removed locations) have not been encouraging.

In mountains and foothills there has been a considerable amount of research on mulches. Mining in these environments creates situations where mulches could be very effective, such as on steep slopes, in harsh environments, or where soils for top-dressing are not available.

A wide variety of natural and commercial mulches have been tested at high elevation sites. The number and variability is so great that it is difficult to select any one type of mulch as superior to others. Holdgro, Lino mesh, burlap, and Ludlo Soil Saver are commercial products that have proved superior in various tests; these have not been tested against one another over a wide variety of sites. The coarser weave of Lino mesh was cited as an advantage.

Natural mulches have proved at least as effective as commercial products in many tests. Brush mulches have been very effective and both studies using this technique were carried out in Alberta. Straw has been successful, at least in the first year.

However, straw loses its effectiveness by the third year and often as early as the second year. When applied mixed with a tackifier (usually asphalt) problems of uniformity of application and movement by wind have occurred. Invasion of weed species is sometimes a problem associated with use of hay. Wood-fibre and tree bark have also been used quite extensively, particularly in the eastern United States. At least in that area, these mulches are available and relatively inexpensive. They have proven to be as effective as straw and some commercial mulches in some instances. A minimum of 1680 kg/ha (wood-fibre) is recommended. These mulches are not recommended for unstable slopes and are more useful for erosion control than plant establishment. In fact, wood bark has been recommended for its usefulness in preventing invasion of weedy species. Sawdust has been used as a mulch, and while giving acceptable results it is susceptible to removal by wind.

The use of soil stabilizers is not recommended in place of mulches. The effect on seedling establishment is limited and may often be detrimental. Generally, physical effects on soil are not beneficial (colour, impermeability, friability) although stabilizers sometimes provide a beneficial chemical effect. Stabilizers used in combination with mulch have improved the effectiveness of the mulch, but generally not sufficiently to warrant the added expense. Stabilizers are definitely not required for establishment during cool, moist seasons (except on steep slopes) but will reduce erosion.

Where topsoil is available, it is superior to mulch. The use of topsoil and mulch in combination is not warranted.

When utilizing mulch, the cost and ease of application are prime considerations. The literature indicates that soil treatments (roughening, loosening of the surface, special grading techniques) should be considered before committing to mulch. These techniques may overcome some disadvantages attributed to mulches (e.g., premature germination).

Studies have indicated that natural materials are equal to or better than synthetic mulches in most cases. Economically, straw and hay are best in terms of both protection and encouragement of plant

growth if resulting weeds or fire hazards are not a problem. Hydraulic mulching provides a weed-free mulch of low fire hazard, with potential labour-saving in application. Wood residues such as bark or wood chips are easier to apply, longer lasting and less susceptible to blowing or fire than straw or hay. Disadvantages are that they may easily discourage plant growth if applied at excessive rates, may reduce pH if material is strongly fermented, and are less effective per unit weight than straw. Fabrics and mats may be very effective if properly anchored; however, excessive erosion beneath the mat may occur on rough surfaces. Mats also require labour intensive application.

There may be local problem areas that warrant expenditure to obtain immediate and lasting results. In such cases, soil stabilizers and more elaborate mulching techniques may be justified. Choice of mulch depends upon site characteristics, species requirements, availability, and cost and need for equipment. No species/mulch interaction studies were encountered in the literature reviewed. This may be a profitable area for further research.

Mulches have not been used extensively in plains areas. Generally, reclaimed sites are larger and costs prohibitive. As well, steep slopes are less common than in mountainous regions. Other cultural treatments, such as topsoiling, fertilization, and irrigation are favoured and can be practiced in a managed cash crop system. Mulches do not appear to add sufficient benefit to warrant extra cost.

Mulching studies in areas not closely related to the oil sands, mountains, or plains have been carried out primarily in the eastern and mid-western United States. Most studies do, however, support observations in the three named physiographic regions. Natural material such as straw, bark, and wood-fibre are generally recommended as equal to or better than synthetic products.

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35. IRRIGATION FOR ESTABLISHMENT OF GRASSES AND FORBS

Irrigation is an important part of the reclamation activities in arid regions such as the Northern Great Plains and southern deserts of the western United States. Irrigation is used as a temporary measure to enhance germination, help establish cover, improve root growth and distribution, and increase soil moisture reserve. The USDA, Forest Service (1979) lists the following points for consideration when irrigation is contemplated:

1. The mined area should receive less than 25.4 cm of precipitation annually.
2. Water rights should be acquired to allow the use of irrigation water by the reclamation manager, providing sufficient water is available.
3. The water requirements of the plants dictate that irrigation must be used.
4. The area receives more than 25.4 cm of annual precipitation, and irrigation water is relatively inexpensive and available, such as from runoff or natural ponding. Water rights may affect the possibility of using these water supplies.

"The amount and frequency of irrigation depends on the amount and intensity of natural precipitation, mine spoil make-up, density of plant cover desired, the species' water requirements, other applied cultural practices, and the availability of labor and funds" (USDA, Forest Service 1979:51). Ries and Day (1978) have noted that there are very few data on the amount and frequency of irrigation required for many species. Techman Ltd. (1979) discussed costs of various irrigation systems employed in Labrador, Saskatchewan, and British Columbia.

Mine spoil characteristics are an important point to consider, especially if spoil amendments such as mulching or grading and shaping are part of the reclamation practice. If irrigation is considered, mine spoils could be engineered to provide the best possible watering medium. For example, water readily infiltrates sandy soils, soils high in organic matter, and uncompacted soils, whereas infiltration is poor in clay soils

or soils low in organic matter. On the other hand sandy soils have less water retention capacity than clay soils. These factors must be balanced against one another to help determine the optimum irrigation plan (USDA, Forest Service 1979).

In addition to infiltration/retention characteristics, spoil topography determines the effectiveness of irrigation. Steep slopes intensify droughty conditions by rapidly draining away soil moisture and by accelerating runoff causing erosion (Bengson 1977). May et al. (1971), using a sprinkler irrigation system to enhance germination of grasses seeded on the steep slopes of coal spoils in Wyoming, found that erosion caused by running water was a major problem.

Mine spoil chemistry and irrigation water chemistry are important in determining the potential for irrigation. Many subsurface and some surface water supplies have high sodium contents making it important to irrigate carefully (Packer and Aldon 1978). Ries and Day (1978) list the following water chemistry characteristics as important for irrigation: "...(i) total concentration of soluble salts, (ii) relative proportion of Na to other cations, (iii) concentration of B or other toxic elements, and (iv) under some conditions, the bicarbonate concentration as related to concentrations of Ca plus Mg...."

There are two main methods of irrigation: (1) sprinkler and (2) drip. Subsurface irrigation systems, designed to emit water into spoils just below the surface have not been used to any great degree in the United States (Packer and Aldon 1978). Several papers have been written on the pros and cons of the two types of irrigation systems (USDA, Forest Service 1979; Anonymous 1978; Ries and Day 1978; Bengson 1977; DeRemer and Bach 1977; Bach 1972). Table 35.1 shows some of the advantages and disadvantages of each system.

Sprinkler systems have proven extremely satisfactory for supplemental irrigation of new grass stands (Packer and Aldon 1978). When used with emitters set for fine spray, the small drops, approaching a mist, greatly reduce the simulated raindrop impact on the soil surface and so facilitate infiltration and reduce erosion. In addition to the advantages listed in Table 35.1, sprinkler systems are adaptable to

Table 35.1. Advantages and disadvantages of drip and sprinkler irrigation systems.

Type of Irrigation System	Advantages	Disadvantages	Comments
Drip irrigation	Uses 1/3 less water	If water contains high sediment level it will clog the lines, unless well filtered	Also called trickle irrigation
	Evaporation is minimal		Plant densities will be less; this can be a disadvantage, but not always
	Amounts of water can be placed directly where wanted	It water is high in salt, salt deposits can build up around the emitter openings	Adequate filtering system crucial
	Especially useful steep slopes, under power lines (because it is safer), between buildings, on critical areas	Labour intensive	Three types of emitters; spitter (puts out a spray); single (puts small amount in local place); and bi-wall (plastic tubing with pin-prick opening to emit water)
		Less easy to move	
		Shorter life span than sprinkler system	
	Moves salts away from plant roots	Higher costs than sprinkler	
	Well suited for woody plants		A portable drip system, using an 1890 L tank has been developed by the Rocky Mountain Station at Albaquerque
Sprinkler irrigation	Less filtering needed	More evaporation will occur	Choose between solid set or movable
	Less expensive than drip	Need larger water supply	Higher plant densities possible
	Less labour intensive	Frequency of application higher than drip	
	Longer life		
	Easier to move, more flexible		

Source: USDA Forest Service (1979).

irregular topography and provide a relatively uniform distribution of water (Ries and Day 1978).

Sprinkler systems are also highly desireable if the goal of irrigation is to leach salts from spoils. Ries and Day (1978) noted that leaching is not an extensively used reclamation tool in the West because of legislation requiring topsoil replacement and due to the absence of sufficient water; however, some work has been done. Harbert and Berg (1974) used a sprinkler system to leach salts from spent oil shales in Colorado. Salts were reduced to low levels; however, resalinization occurred on some of the shales.

Drip irrigation was developed in Israel in the 1960s for agricultural systems. Its use in arid land reclamation was pioneered by the California Highway Department in revegetation of high berms (Bengson 1977). Drip irrigation has been defined as "...the frequent or daily application of water to localized areas through emitters at a rate that will balance water used by evapotranspiration....The system is composed of a plastic pipeline on the surface with emitters placed at some distance apart. Plants are placed at each emitter and the amount of water for their growth is controlled by adjusting the emitters or the pressure in the water line...." (Ries and Day 1978).

Bach (1972) noted that the most common rate of application is 3.8 L per hour per emitter. Over a 24 h period this rate of application allows a slow, deep penetration of water into the spoil with some lateral movement, but no runoff.

Although application rates are low, soluble materials, including nutrients, are leached from the spoils in the area of the plants. For this reason a well designed system should include an injection pump for nutrient solutions to replace essential elements leached from the root zone (Bach 1972).

One of the problems encountered with both of these systems in arid regions is damage caused by animals searching for water. Researchers at the Anamax Mine in Arizona solved this problem by setting out special animal-watering spots along the pipes, which substantially reduced damage (Anonymous 1978). The same study noted that a switch from

daytime to night-time sprinkler irrigation at the Anamax Mine reduced evaporation losses as expected; however, rattlesnakes were found to be attracted in numbers to the water at night.

As mentioned previously, irrigation efficiency is dependent largely on spoil characteristics. Efficiency may be improved by: (1) changing soil infiltration/retention capability through the addition of mulches; (2) changing macrotopography by reducing slopes or creating terraces where erosion problems are reduced; and (3) changing microtopography around plants through the use of catch-basins and troughs to take advantage of all moisture applied.

35.1 MOUNTAINS AND FOOTHILLS REGION

Farmer, Richardson and Brown (1976) studied the effects of irrigation, topsoiling, mulching, and fertilization on establishment and growth of three grass mixes sown on acid (pH 3.5 to 6.3) copper-cobalt spoils near Salmon, Idaho (elevation = 2378 m). The three main treatments were irrigation, topsoiling, and a control (raw spoil). Superimposed on these plots were fertilization and mulching treatments. The study was extremely complex and the reader is encouraged to read the paper for more details on the methods and results. The same experimental design was used by Farmer et al. (1974) and Richardson et al. (1975) on coal spoils in Montana.

Plot preparation, seed mixes and rates were discussed in Chapter 33.

From June through September 1973 (the first growing season), water was applied on the irrigated main plot in three weekly applications of 0.6 cm each. From June through September 1974 water was applied "as needed" on the basis of visual observations of plant turgor and length of time since the last irrigation or rainfall. Irrigation water was obtained from a nearby creek, hauled to the research site, and applied through a sprinkler irrigation system with a high degree of uniformity.

Data on seedling emergence and estimated dry matter production were collected in the first and second growing seasons but not statistically analyzed. In both seasons the yield of all mixes was

better on the irrigated plots than on the control plots (Figure 30.1). Most of the topsoiled plots had greater yields than the irrigated plots in both years.

From this study it was concluded that the use of irrigation is of questionable value but could not be completely dismissed. Irrigation appeared most useful when combined with mulch. The authors noted that further data on the effects of withdrawing the irrigation were needed.

Jensen and Hodder (1979) studied the effects of a single and double irrigation on establishment of a grass/legume mix sown on a roadside cut near Melrose, Montana (elevation = 1600 m). The study area was located on a large backslope with a north-south orientation, west exposure, and a 5:1 slope ratio. Subsoil exposed by the backslope consisted of a complex pattern of randomly oriented layers of medium size particles of sand, gravel-sand mixtures, and clay. The roadside cut was covered with a 10 cm layer of topsoil salvaged from the adjacent roadway prior to road construction. Topsoil was characterized as loamy sand and the subsoil as sandy loam.

Following fertilizer application in July, a chisel plow was used to till the study area twice in opposite diagonal directions. Table 34.8 shows the grass, legume, shrub, and cereal grain seed mixture formulated for broadcast seeding the treatments. The perennial species seed mixture was broadcast seeded at 21 kg/ha pure live seed (P.L.S.) and the annual species, Hordeum vulgare cv. Horsford was broadcast seeded at 13 kg/ha (P.L.S.). Surface amendments (gouging, three mulches) were applied to plots then the mix was broadcast seeded.

Following treatment applications, an agricultural type impact head sprinkler irrigation system was installed on the plots. The main pipe (20 cm diameter) with lateral connectors and control valves was positioned between the two study area locations. The site was covered by four parallel, equally spaced, lateral lines each running through all treatment plots. On 24 July, 3.8 cm of water was applied to all treatments at a rate of 0.6 cm/h. Due to variation among sprinkler heads and wind conditions, the total application rate was estimated to have

varied ± 10%. On 17 August, a similar application of 3.8 cm of water was applied only to the "double application" irrigation treatments.

Total cover and plant density data were collected in November of the first growing season, July of the second, and September of the third season. Total cover in the first season was significantly greater on the double irrigated plots than on the single irrigation plots (Table 34.8). However, the individual plant types (Hordeum, grasses, or legumes) were significantly improved by double irrigation. There were no differences in total cover in subsequent years; both cover and density decreased in all plots with time.

From this study Jensen and Hodder (1979:76-77) made the following recommendations:

1. "When a suitable quantity of irrigation quality water is available, irrigation with an agricultural type sprinkler system should be implemented. The commonly available sprinkler irrigation system using lateral water lines with uniformly spaced vertical risers and impact type sprinkler heads was determined to provide good results. Although not evaluated, the authors believe that the use of a self propelled water cannon type of sprinkler system operated from the road surface may prove to be very efficient and effective."
2. "To derive maximum benefit from limited irrigation, sufficient quantities of water must be applied with each application to assure that the majority of the water percolates well into the surface soil. Light soil surface applications of water are lost almost entirely through atmospheric evaporation. Utilization of light intensity daily sprinkling is discouraged."
3. "Irrigation of roadsides can be successfully accomplished with large capacity water hauling vehicles. However, the cost of applying large quantities of water and the limited availability of the equipment may make the operation impractical on all but small areas."

35.2 PLAINS REGION

Richardson et al. (1975) and Farmer et al. (1974) studied the effects of irrigation, topsoiling, mulching, and fertilization on establishment and yield of three grass mixes sown on coal spoils (pH = 7.0 to 8.8) in south-eastern Montana. The main plots were the irrigated and topsoiled plots and a control (raw spoil) plot. Superimposed on these treatments were the mulch and fertilizer treatments. As the study was complex the reader is encouraged to read the reports for more detail on methods and results.

Irrigation was applied from 18 May to 04 October at a rate of 3.8 cm per week in five daily applications of 0.76 cm. The sprinkler system was completely automated and provided a uniform application (uniformity coefficient 0.97).

The study site was approximately 61 m from a coal test pit 24.4 m deep, from which ground water was pumped and used as the irrigation water supply. This ground water was of low quality for irrigation purposes, principally because of the high sodium content. Other sources of irrigation water were considered impractical because of costs, transportation difficulties, or water right problems. The Decker Coal Company had been successfully using the pit water in short term irrigation projects.

During the second week of August, two months after irrigation started, soil analyses on the irrigated plot showed that conditions for plant growth were deteriorating. The pH near the soil surface was nearly 10, and exchangeable soil sodium had increased by 100 percent. To counteract this trend, calcium chloride was applied to the irrigated plot at the rate of 3024 kg/ha. The calcium chloride was applied over a two-week period through the irrigation systems as a saturated solution mixed 1:60 with the irrigation water.

The three seed mixes used in this experiment were a native mix, an introduced mix, and a native plus introduced mix sown at 28.6 kg/ha (Table 30.3). Emergence was assessed in the spring and production was estimated in October of the first growing season.

Irrigated plots produced better yields under all treatments than the control plots (Figure 34.2). Sub-plots that were irrigated, fertilized and mulched had the greatest yields of all treatments. Otherwise, top-dressed subplots outperformed irrigated plots. There were no indications that the use of low quality water adversely affected yields during the first growing season; however, there were marked changes in exchangeable sodium in the soil.

Richardson et al. (1975) has reported on the preliminary second season yield results. Plots were irrigated in the second season, but at a substantially reduced rate in an attempt to encourage greater root penetration. Yields in the irrigated plot were again higher than those in the control plot (Figure 34.3). The highest yielding treatments were the irrigated, fertilized, and mulched subplots. However, top-dressed plots otherwise produced better yields than comparative irrigated plots. Yields in the fertilized plots were substantially greater in the second season than in the first. Yields in the unfertilized plots were unchanged or slightly lower.

From these studies Richardson et al. (1975) have concluded that irrigation alone is not a satisfactory amendment for establishing good stands of grass. When combined with fertilization and mulch, irrigation produced the greatest yields in the first season but there were few differences between the irrigated and topsoiled plots by the second season.

DePuit (1980) and DePuit, Coenenberg and Dollhopf (1979) studied the effects of irrigation and soil amendments on establishment of a grass/legume/shrub seed mix sown on coal spoils at the West Decker Mine, Montana (elevation = 1076 m). Replaced overburden at the site was considered sodic and moderately saline, with an average sodium absorption ratio of 22.9 and electrical conductivity of 3.4 mmhos/cm.

Spoils were contoured and plots set out in October, 1977. Plots were then ripped and amendments (gypsum, $CaCl_2$, NH_4SO_4) applied. Approximately 70 cm of non-sodic, non-saline topsoil was subsequently applied to all plots.

Following topsoiling, the seed-bed was prepared by initially chisel plowing and subsequently disc plowing. The seed-bed was then harrowed with a double gang of wire rollers. Study plots were seeded on 14 November 1977 using a Brillion "sure stand" grass seeder. The seed mixture was composed of predominantly native plant species (Table 35.2), and was applied at an overall rate of 28 kg/ha of pure live seed. Following seeding, all plots were hydromulched with wood-fibre at a rate of 2242 kg/ha.

Study plots were uniformly fertilized on 13 June 1978 and again on 06 September 1978. The site was mowed for weed control purposes on 08 August 1978.

A sprinkler irrigation system was established in the spring of 1978 for application of supplemental water to those plots to be irrigated. Water was obtained via pipeline from the nearby Tongue River Reservoir. The period of supplemental irrigation during 1978 extended from 03 June to 29 September. Approximately 10 cm of irrigation water was applied to the irrigated plots over 6 to 7 day periods at two week intervals throughout this period. A total of approximately 70 cm of supplemental water was applied during the 03 June to 19 September 1978 period. Approximately 85 cm was applied from June to September in the second season.

Data on plant biomass and stand composition were collected at the end of both growing seasons and the Shannon-Weaver diversity index calculated from these data.

In general, first season irrigation significantly improved productivity of the perennial grasses and increased overall stand diversity by means of greater evenness of cover distribution among species (Table 35.3). While canopy cover of perennial grasses was improved by irrigation (29.6% versus 16.4%) there was little difference in species frequency, indicating that the stimulation of perennial grass productivity by irrigation was primarily due to increased plant vigour and not increased establishment success. Species significantly

Table 35.2. Seed mixture used for soil amendment-irrigation study, Decker, Montana, October, 1977.

Common Name	Scientific Name	PLS Seeding Rate: kg/ha
Western wheatgrass	(*Agropyron smithii*)[a]	7
Thickspike wheatgrass	(*A. dasystachyum*)[a]	7
Slender wheatgrass	(*A. trachycaulum*)	3
Whitmar beardless wheatgrass	(*A. inerme*)[a]	1
Pubescent wheatgrass	(*A. trichophorum*)	1
Green needlegrass	(*Stipa viridula*)[a]	5
Prairie sandreed	(*Calamovilfa longifolia*)	1
Blue grama	(*Bouteloua gracilis*)[a]	1
Smooth bromegrass	(*Bromus inermis*)	1
Eski sainfoin	(*Onobrychis viciaefolia*)	0.5
Fourwing saltbush	(*Atriplex canescens*)[a]	trace to 1
		28

Source: Adapted from DePuit, Coenenberg and Willmuth (1979).
[a] Native to Montana

Table 35.3. Mean above-ground plant community characteristics of summer irrigated and non-irrigated plots during the first (1978) and second (1979) growing seasons, soil amendment-irrigation study, Decker, Montana.

	1978		1979	
	Irrigated	Non-irrigated	Irrigated	Non-irrigated
Peak Aboveground Biomass[a] (kg/ha):				
Perennial grasses	245.2a	141.1b	4422.9a	1195.0b
Annual grasses	14.6	5.6	11.2	10.1
Legumes[d]	41.4	38.1	1529.9a	629.4b
Weedy forbs[e]	656.3	763.8	19.0b	421.1a
Other forbs	11.2	11.2	10.1	7.8
Total	968.8	959.8	5993.1a	2263.5b
Stand Composition (%):[b]				
Cool season perennial grasses	43.0	21.5	73.4	52.7
Warm season perennial grasses	4.0	2.4	1.8	3.7
Legumes[d]	8.6	5.9	22.6	16.4
Weedy forbs[e]	43.4	68.2	0.7	26.7
All other species	1.0	2.0	1.5	0.5
Diversity:[b,c]				
Shannon-Weaver Function (H')	.8861	.7720	.8325	.8957
Evenness	.6507	.5456	.5816	.6774
Richness	23	26	27	21
Water Supplied (cm):				
Growing Season[f] Precipitation	33.8	33.8	18.0	18.0
Summer[g] Irrigation	69.9	ND	85.1	ND
Total	103.7	33.8	103.1	18.0

Source: Adapted from DePuit (1980).

[a] Biomass values followed by different letters significantly different at 5% level.

[b] Based upon canopy cover data

[c] Shannon-Weaver Function (H') is a synthetic diversity index (Shannon and Weaver, 1973) in which higher index values denote higher overall diversity (log base 10 was used in calculation); richness represents total numbers of plant species counted in sample quadrats; evenness represents the evenness of cover distribution among species present (obtained by dividing H' by $\log_{10}$ of richness).

[d] Primarily yellow sweetclover (*Melilotus officinalis*)

[e] Primarily Russian thistle (*Salsola kali*) and summercypress (*Kochia scoparia*)

[f] April-September

[g] June-September

stimulated by first season irrigation included Agropyron trichophorum, A. dasystachyum, A. trachycaulum, Bromus inermis, and Bouteloua gracilis.

Sustained (two year) irrigation during the drier year of 1979 produced a greater number of significant biomass differences, with perennial grass, legume, and total biomass significantly higher under irrigation (Table 35.3). Conversely, weed biomass was significantly reduced under irrigation, presumably due to competitive inhibition by perennial grasses and legumes. However, overall stand diversity and evenness were reduced in irrigated plots by 1979, since the irrigated stand had become overwhelmingly dominated by a small number of highly responsive cool-season species, primarily A. trachycaulum, A. smithii, Bromus inermis, and Melilotus officinalis. Certain warm season grasses, especially Bouteloua gracilis and Calamovilfa longifolia, had become specifically retarded by two years of irrigation.

Striking differences in root biomass between irrigated and non-irrigated plots were evident (Fig. 35.1), after two years of irrigation. Total root biomass was significantly lower in irrigated plots, primarily due to effects of frequent soil saturation and ponding, which may have reduced soil aeration to the point of limiting root growth. Root:shoot ratios were also lower in irrigated than in non-irrigated plots. In adddition, roots tended to be far more concentrated toward the soil surface in irrigated plots, while non-irrigated plots exhibited relativeley greater proportions of total root biomass at intermediate and denper depths.

From this study the researchers found positive effects of first year irrigation in terms of productivity, stand composition, and diversity, while sustained (second year) irrigation was desirable only in terms of increased productivity. Furthermore, less productive, shallower root systems after two years of irrigation could signal stand deterioration if plants were exposed to more xeric conditions when irrigation is terminated. Therefore, the authors felt temporary irrigation for establishment could be the most viable technique if establishment of a diverse, climatically adapted plant community was the ultimate reclamation goal.

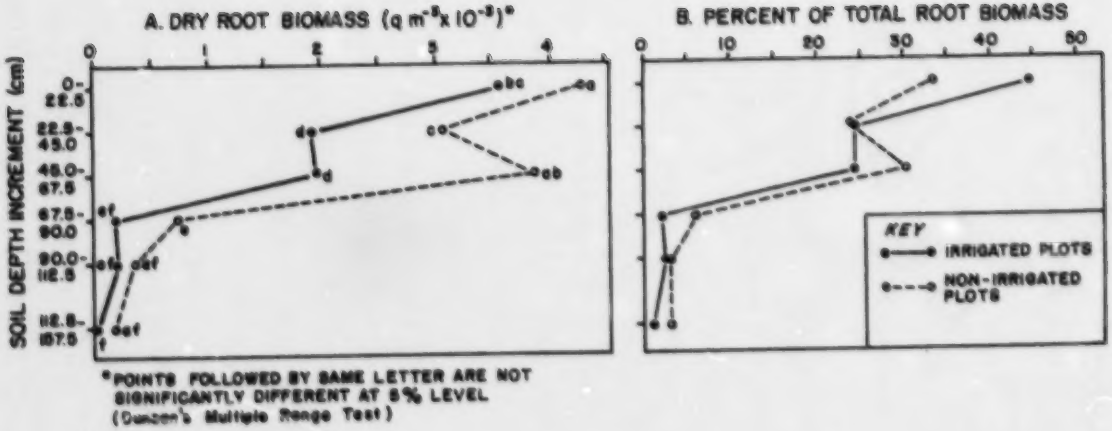

Figure 35.1. Mean total belowground (root) biomass (A) and biomass distribution (B) in irrigated vs. non-irrigated plots in the second (1979) growing season, Soil Amendment Irrigation Study, Decker, MT.

Source: DePuit (1980)

DePuit (1980) has also reported on preliminary data from an experiment to determine the effects of irrigation on a grass/forb/shrub mix seeded in spring or summer onto sodic coal spoils at Colstrip, Montana. A constant native seed mixture of five cool-season and five warm-season perennial grasses, plus three shrubs and four forbs, was seeded at both a "normal" early spring date and an early summer (mid-June) date. Within each seeding date a main plot and four subplots were established. The first subplot was left as a non-irrigated control, and the second, third, and fourth were subjected to one, two and three months of summer irrigation, respectively. Irrigation was initiated in early July.

From the data in Table 35.4 it can be seen that the spring seeding was far superior to the summer seeding in both irrigated and control plots. Irrigation improved yield in all cases, though stand composition, except for warm-season annual grasses, was not markedly changed by the addition of extra water. Perennial grass and legume productivity increased with increased irrigation. DePuit noted that accidental grazing of plots removed data for the three month irrigation trial but suggested the trend of increased productivity would have continued.

DePuit also noted that these preliminary data indicated the beneficial effects of irrigation in promoting vegetation establishment and effectively extending the season of seeding by improving summer seeding establishment rates. Summer seeding, coupled with irrigation, appeared to be an effective means of establishing native warm-season perennial grasses in mixture with cool-season species. In addition, the varied spring-summer seeding dates, made possible by irrigation, may allow manipulation of invading species, such as Melilotus officinalis and Salsola kali, and annual grasses. DePuit noted that the final evaluation of this reclamation strategy will only be known after future data collection when irrigation is halted.

Ries et al. (1979) also investigated the interaction between supplemental irrigation and seeding dates in a study conducted at the Northern Great Plains Research Center, Mandan, North Dakota. Plots were

Table 35.4. First year (1979) plant community characteristics as influenced by date of seeding and irrigation treatments, seeding date-irrigation duration study, Colstrip, Montana.

	Spring Seeded Plots				Summer Seeded Plots			
	Non-irrigated	Irrigated for: 1 Month	2 Months	3 Months	Non-irrigated	Irrigated for: 1 Month	2 Months	3 Months
Aboveground biomass (kg/ha):								
Perennial grasses	65.0	415.5	1012.5	ND	26.9	175.8	212.8	ND
Annual grasses	6.7	261.0	459.2	ND	0	379.7	308.0	ND
Legumes[c]	48.2	370.7	1174.9	ND	0	14.6	43.7	ND
Shrubs	8.9	51.5	122.1	ND	2.2	19.0	6.7	ND
Weedy forbs[d]	45.9	142.2	168.0	ND	0	0	3.4	ND
Other forbs	23.5	417.8	267.7	ND	0	34.7	142.2	ND
Total	198.2	1658.7	3204.2	ND	29.1	623.8	716.8	ND
Stand composition (%):[b]								
Cool season perennial grasses	39.5	39.6	31.8	43.4	9.1	7.8	11.5	36.4
Warm season perennial grasses	2.3	2.2	1.7	3.6	63.7	20.6	23.4	20.3
Cool season annual grasses	5.7	6.6	2.8	7.1	0.0	0.6	6.6	3.0
Warm season annual grasses	0.0	10.3	5.7	1.4	27.3	65.7	44.0	29.8
Non-seeded legumes[c]	30.5	29.4	47.1	32.9	0.0	0.0	2.3	0.3
Shrubs	2.5	1.1	0.7	1.6	0.0	0.4	T[e]	0.6
Weedy forbs[d]	8.2	6.3	1.2	3.1	0.0	1.1	3.4	2.4
Other forbs	11.5	4.5	9.0	6.9	0.0	3.8	8.8	7.2

Source: Adapted from DePuit (1980)

[a] ND = accurate biomass data unavailable due to accidental livestock grazing.

[b] Based upon canopy cover data.

[c] Primarily yellow sweetclover (*Melilotus officinalis*)

[d] Russian thistle (*Salsola kali*)

[e] T = <0.1% composition

prepared in May 1975, on a loam soil which was deep plowed about 75 cm to simulate a disturbed soil condition similar to that occurring where 60 cm of good topsoil is replaced over spoil material after mining. The seed-bed was prepared by discing and leveling the deep plowed area with conventional farm equipment. Treatments of two water levels, two planting dates, and two species mixtures were randomly assigned in the field in a split, split-plot design with three replications.

The introduced mixture was seeded at a rate of 18.5 kg/ha of pure live seed composed of 26% Bromus inermis, 37% Elymus junceus, 9% Medicago sativa, and 27% Agropyron trichophorum. The native mix was seeded at a rate of 18.0 kg/ha of pure live seed composed of 20% Agropyron trachycaulum, 20% Agropyron smithii, 30% Bouteloua curtipendula, and 30% Bouteloua gracilis.

Plots were tilled in May before seeding on 29 May and again in mid-July before seeding on 31 July. Plots that were seeded in July received the same water treatments before and after seeding as were received by plots seeded in May. Seeding of both mixtures was done with a plot cone seeder with double-disc openers and pack wheels. Bouteloua gracilis was hand seeded over the plots and raked in because of its fluffy nature and tendency to plug the mechanical seeder. All plots were rolled with a small packer after seeding.

Water treatments began on 01 June. The two levels were natural precipitation (Precipitation 1), and natural precipitation plus sufficient water added twice a week to simulate precipitation received in a wet year which occurs naturally one out of every ten years (Precipitation 2) (Table 35.5). Added water was applied with a rotating boom plot irrigator which allowed excellent control of rate and distribution of water over the plot.

Density and dry matter production were measured seven weeks after seeding for both seeding dates and both seed mixtures. For the introduced species, plant density (four species combined) was not affected by precipitation (seeding dates combined) or by seeding date (precipitation rates combined) (Figure 35.2). Average production was higher in the supplemental irrigation plots (7.5 versus 35.5 g/m^2).

Table 35.5. Natural precipitation (Precipitation 1) and natural precipitation plus supplemental irrigation (Precipitation 2) supplied to plots at Mandan, North Dakota.

Month	Precipitation 1	Precipitation 2
June	13.6 [a]	15.8
July	1.7	11.2
August	1.6	10.2
September	2.1	7.6
Total	18.9 [b]	44.7

Source: Adapted from Ries et al. (1979).

[a] Measured in cm

[b] Long-term average is 22.28 cm

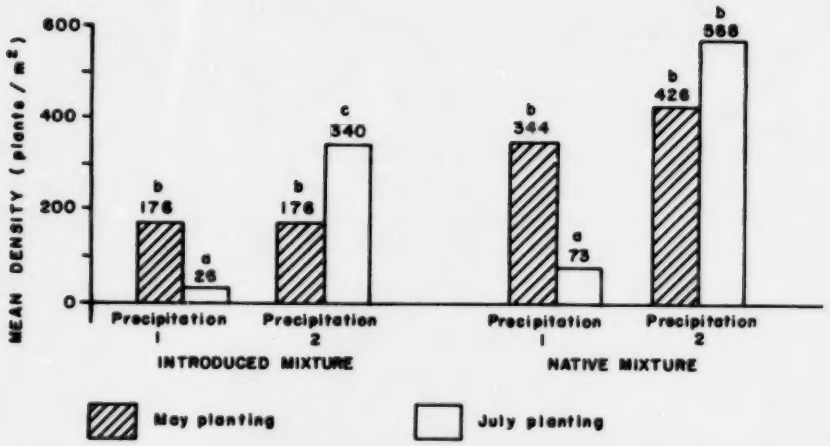

Figure 35.2. Effects of precipitation and planting date on density of introduced and native mixtures sown on a simulated reclaimed area, at Mandan, North Dakota. Means with different letters differ significantly at the 5% level of probability.

Source: Ries et al. (1970)

There were, however, significant interactions between precipitation rates and seeding dates for the mix and for the individual species. Supplemental irrigation improved density of the summer seeded mix but not of the spring seeding (Figure 35.2). Density of Elymus junceus and Medicago sativa were significantly greater with increased irrigation. The interactions between seeding date and precipitation were significant for both Bromus inermis and Elymus junceus (Table 35.6).

For the native mix, mean plant density was significantly increased by supplemental irrigation (Figure 35.2). Production was also improved from 8.6 g/m^2 for Precipitation 1 to 19.4 g/m^2 for Precipitation 2. There were significant planting date-irrigation rate interactions for both the mix and individual species. Density of the mix was increased by supplemental irrigation on summer seeded plots but not on spring seeded plots (Figure 35.2). Density of Agropyron smithii and Bouteloua gracilis were significantly increased by supplemental irrigation. Bouteloua curtipendula showed a significant interaction between planting date and irrigation (Table 35.6). Non-seeded plant densities were reduced under irrigation and when plants were seeded in July.

From this study Ries et al. noted that the use of supplemental irrigation effectively lengthened the seeding season by allowing late seeded plots enough moisture to ensure germination. These results are similar to those of DePuit (1980). The authors also pointed out that the native species in this trial benefitted more from irrigation than the introduced species.

Four studies by Aldon and Springfield (1975, 1977), Aldon, Springfield and Sowards (1976), and Aldon (1975) examined sprinkler and drip irrigation systems for establishment of grasses and shrubs on coal spoils near Farmington, New Mexico. Data on shrub establishment is presented in Chapters 37 and 38.

In the first sprinkler study, two sites were selected, both of which were characterized by relatively dark, shale-derived material. Site One consisted of steep-sloped spoils that were graded in a minimal way to provide artificial floodways approximately 3.6 m wide with a 3 to 5 percent gradient. Site Two, about 0.8 km north of the first site, was

Table 35.6. Density means (plants/m^2) for individual species for both mixtures as related to precipitation, planting date, and interactions, Mandan, North Dakota.

Mix	Species	Precipitation (P)[a]			Planting dates (P)[b]			Interactions				
		1	2	P>F[c]	May (M)	Jul (J)	P>F	P1M	P1J	P2M	P2J	P>F
Introduced	Brin[d]	39	112	.2198	60	90	.3698	73	4	47	176	.0297*
	Elju	43	78	.1167*	60	64	.7152	78	13	39	116	.0096*
	Mesa	9	43	.0919*	30	21	.5773	13	0	43	43	.5773
	Agtr	13	26	.5543	30	9	.1513	13	13	47	4	.1963
	Total[f]	104	259		180	184						
	Others	103	133	.3613	207	26	.0014*	207	0	211	52	.2746
Native	Agsm[e]	9	39	.1135*	17	30	.5553	13	4	17	60	.2063
	Agtra	73	90	.5111	112	56	.1470	120	26	99	82	.2828
	Bocu	78	120	.5346	90	108	.6366	116	43	64	176	.0787*
	Bogr	47	250	.1019*	168	125	.2604	95	0	245	250	.1905
	Total[f]	207	499		387	319						
	Others	112	86	.0727*	181	17	.0005*	224	0	138	30	.0050*

Source: Adapted from Ries et al. (1979).

a Precipitation 1 = natural precipitation, 1975.
Precipitation 2 = natural precipitation plus added water to equal natural precipitation received in a wet year (10% frequency).

b Planting date May = seeded May 31, 1975, with May tillage.
Planting date Jul = seeded July 31, 1975, with July tillage.

c Calculated probability of greater F value.

d Species are: Brin=Bromus inermis, Elju = Elymus junceus, Mesa = Medicago sativa, Agtr = Agropyron trichophorum, others = any nonplanted species, primarily annual weeds.

e Species are: Agsm = Agropyron smithii, Agtra = Agropyron trachycaulum, Bocu = Bouteloua curtipendula, Bogr = Bouteloua gracilis, others = any nonplanted species, primarily annual weeds.

f Calculated from original data.

* Significant at probability level P≤.10 or less.

graded to an undulating topography consisting of hills and valleys. The valleys were considered floodways.

At each site, a pair of comparable floodways were prepared by grading with a bulldozer. Erosion checks were installed in one floodway of each pair to reduce or eliminate sediment movement and gully formation. However, no sediment movement was detected on either plot.

Five randomized blocks were marked off in each floodway. Each block consisted of two plots, one for Sporobolus airoides and the other for Atriplex canescens.

The S. airoides plots were divided into three subplots. Methods of seeding, assigned to the subplots at random were:

1. In small collars 3.8 cm high and 8.9 cm in diameter and in large collars 5.1 cm high and 16.5 cm in diameter.
2. Furrows 5.1 cm wide, 5.1 cm deep, and 3 m long.
3. Straw was spread at the rate of 2.2 t/ha, then disced into the top 7.6 cm of soil. Seeds were then broadcast over the plot.

The rate of seeding for all methods was 1548 seeds/m^2.

Sprinkler irrigation systems were arranged in each floodway. Water was applied at a rate of 1.3 cm twice a week; about 25 cm was applied during the first growing season. No water was applied the second growing season.

In the second study, water was applied to plots through thirty 5.1 cm diameter lines spaced 12.2 m apart along the long axis of the area. Rainbird full circle sprinkler heads were placed in a diamond pattern at 12.2 m intervals along each line. Each line contained 18 sprinkler heads. Total gross applications ranged from 18.6 cm to 26.4 cm. The effective applications (net) were calculated at 65% of the gross amounts to adjust for evaporation and system efficiency (Table 35.7).

The plots were direct seeded in mid-May with three mixes: (1) Mix 1, S. airoides and Hilaria jamesii at 2.8 kg/ha each; (2) Mix 2, Sporobolus airoides and H. jamesii at 2.8 kg/ha and Atriplex canescens at

Table 35.7. Emergence of Sporobolus airoides and Hilaria jamesii under five sprinkler irrigation treatments near Farmington, New Mexico.

Water applied (cm/ha)		Number of plants per square metre					
		Sporobolus airoides		Hilaria jamesii		Total	
Gross	Net[a]	1974	1975	1974	1975	1974	1975
18.6	12.1	31.8	ND[b]	4.7	ND[b]	17.6	ND[b]
23.7	15.4	40.4	11.1	10.8	0.4	51.2	11.5
18.3	11.9	28.2	4.0	19.7	0.5	47.8	4.5
26.4	17.2	36.7	6.1	16.9	0.4	53.5	6.6
22.8	14.8	28.2	5.9	12.7	0.1	40.9	6.0

Source: Adapted from Aldon, Springfield and Sowards (1976).

[a] Net amount applied (65% of gross).

[b] Not sampled in 1975.

5.32 kg/ha; and (3) Mix 3, S. airoides and H. jamesii at 8 kg/ha plus A. canescens and Oryzopsis hymenoides at 4.2 kg/ha.

Seed of S. airoides and H. jamesii were broadcast with a mechanized cyclone seeder, whereas seeds of A. canescens and O. hymenoides were seeded with a rangeland drill. A native hay mulch was then distributed with a mechanized spreader at the rate of 0.7 t/ha and anchored by crimping.

Emergence of S. airoides was much better in the first study although the irrigation rate was no greater than in the second. An average of 86 S. airoides plants per m^2 were alive over all treatments after the first growing season. Twenty-eight percent of these survived after two years in spite of half-normal precipitation levels. In the second study, emergence of the S. airoides was greatest on plots receiving the highest amount of water (Table 35.7) while emergence of H. jamesii was highly variable. Poor emergence of O. hymenoides was attributed to inadequate moisture availability. Second season survival of S. airoides was again highest on plots that received the most water.

When combined with sprinkler irrigation the best establishment was achieved by planting in small collars. Aldon and Springfield pointed out, however, that this method would not be practical in large-scale reclamation operations. The best practical method was planting in furrows.

In the first drip irrigation study two 30.5 m lengths of 2.5 cm plastic pipe were laid about 6.1 m apart on graded spoil material. Emitters were located at 0.3 m intervals along 18.3 m of each line. Three-month-old transplants of Atriplex canescens and Agropyron smithii, grown by special techniques, were planted alternately at each emitter. Ten transplants of each species, used as controls, were planted between the lines but not watered.

Seedlings were transplanted in mid-September 1973, and watered twice a week until the first hard frost (eight waterings). Discharge rates under gravity feed were 5.3 L per emitter per hour. Each emitter delivered about 15.1 L per watering. Plants were not irrigated in 1974.

The second study tested four application rates varying from 28.4 L/emitter to 49.6 L (Table 35.8) applied from 22 June to 30 August. Drip lines were 366 m long with 18 lines in each subplot running parallel and 3 m apart. There were 3375 emitters, spaced randomly but averaging 1.9 m apart, per subplot.

Under each emitter a shallow basin was scooped out and seeded in mid-June to S. airoides (100 seeds), H. Jamesii (80 seeds) or O. hymenoides (80 seeds). Seeds were covered with 0.6 to 1.3 cm of spoil materials, then mulched lightly with straw. Each species was tested on plots amended with topsoil, gypsum or bottom ash.

In the first study, irrigation significantly improved survival of the Agropyron transplants (Table 35.9) even though planting was done late in the season. The irrigated plants were also substantially larger than the control plants.

Differences in emergence between watering treatments in the second study were significant. The emergence of all three grasses improved almost two-fold with the second rate (30.7 L) over the first (28.4 L; Table 35.8). Aldon, Springfield and Sowards pointed out that while total water supplied to the second set of plots was less than the first the amount supplied in July and August was greater. Emergence improved on the other plots but to a lesser extent. Spoil treatment has the greatest effect on plots receiving the least water.

From these studies, the authors concluded that irrigation was beneficial in establishing grasses on coal spoils in New Mexico but that irrigation schemes, especially sprinkler irrigation, must be applied in conjunction with spoil shaping in order to obtain maximum benefit. Aldon, Springfield and Sowards (1976) noted that best results were achieved with as large a volume of water as possible, especially when the greatest proportion was applied later in the summer.

Aldon, Cable and Scholl (1977) tested the effectiveness of three irrigation systems on establishment of grasses sown on uranium wastes about 104 km north-west of Alburquerque, New Mexico (elevation = 1900 m). Fourteen plots were set out on a 36 to 40% slope on tailings dam. The plots were divided into four blocks of three plots for each irrigation system and two control plots.

Table 35.8. Emergence and survival of plants after one and two growing seasons under drip irrigation near Farmington, New Mexico.

Water level (L)		Sporobolus airoides		Hilaria jamesii		Oryzopsis hymenoides	
		1974	1975	1974	1975	1974	1975
30.7[a]	6.1[b]	37[c]	58	47	9	36	37
28.4	8.7	75	50	78	14	83	65
32.6	17.6	81	62	80	21	85	88
49.6	22.7	87	78	89	33	87	82

Source: Adapted from Aldon, Springfield and Sowards (1976).
[a] Total volume of water applied in June, July and August
[b] Volume of water applied in July and August
[c] Values are means of four surface treatments

Table 35.9. Survival and growth of drip-irrigated Agropyron smithii transplants, in New Mexico. Measurements taken 22 months after planting.

	Irrigated	Control
Survival (percent)	80.0	30.0
Height (cm)	35.3	23.6
Diameter (cm)	7.6	3.3
Size index (ht. x dia.)	268.3	77.9

Source: Adapted from Aldon (1975).

Before the irrigation systems were installed, the dam face was covered to a depth of 15 to 30 cm with a mildly alkaline clay loam alluvial topsoil, with moderately rapid permeability, from the pond area. The dam face was broadcast seeded to: Bouteloua gracilis, Bouteloua sp., Hilaria jamesii, and Sporobolus cryptandrus, 3.6 kg each, and Prosopsis sp., and Sporobolus airoides, 5.4 kg each, for a total seeding rate of 27.5 kg/ha. Seed was raked in an covered with about 3.4 metric tons/ha of grass hay mulch. The mulch was crimped by hand with shovels.

The three irrigation systems being tested were the Spitter Emitter, Submatic drip irrigation system and the Bi-Wall system. The Spitter Emitter system consisted of 12.7 mm polyethylene hose with emitters at 1.9 m intervals, used as a full circle spray. The Submatic system consisted of 12.7 mm polyethylene hose with 0.5 mm drip orifices at 0.3 m spacing. The Bi-Wall system consisted of a dual-chamber polyethylene tube with very small feed holes at 0.3 m intervals.

Irrigation lines were spaced at about 1.5 m intervals down the dam face, running horizontally across the plots on the ground surface, and fed from 5.1 cm feeder lines running down one side of each plot. Numbers of irrigation lines per plot varied from 12 to 17, depending on the downslope plot length.

The water supply system consisted of a 7.6 cm plastic pipe running the length of the dam face, along the top, to which the feeder lines for each plot were attached. A filter, pressure regulator, and pressure valves were installed on the incoming line to filter the well water and control the line pressure at about 1 kg/cm^2. Water application rates for the seven-week period of irrigation are given in Table 35.10.

The plots were irrigated for the first time on 18 June 1976, and were subsequently irrigated three times weekly for the first two weeks until the grass seeds germinated and were well started. At that time the frequency was changed to twice weekly, and the duration of the spray irrigation was reduced 50% because of excessive runoff and erosion. This schedule was followed for the next five weeks, at which time an adequate stand of seedlings had started on all plots except the Bi-Wall. Irrigation was stopped at this time.

Table 35.10. Rates and amounts of water applied by the three irrigation systems, on New Mexico uranium spoils.

System	Rated output (L/hr)	Ground coverage (m^2)	Water applied per irrigation (cm) First two weeks	Water applied per irrigation (cm) Next five weeks	Seven-week total (cm)
Spitter-Emitter	37.85	2.79	5.43	2.72	59.78
Submatic	9.45	.46	2.05	2.05	32.80
Bi-Wall	3.78	.46	1.64	1.64	26.24

Source: Adapted from Aldon, Cable and Scholl (1977).

Table 35.11. Perennial grass density and height at the end of the growing season, and moisture penetration and erosion for three irrigation systems after four weeks of irrigation on New Mexico uranium spoils.

Irrigation system	Grass		Moisture	Erosion	
	Density plants/m^2	Height cm	Penetration cm	Volume m^3/ha	Gullies no./30 m
Spitter Emitter	396.1 a	9.8 a	28.0 a	17.9 a	11 a
Submatic	256.2 b	9.5 b	23.6 b	5.8 b	36 b
Bi-Wall	123.8 c	6.4 c	14.6 c	.7 c	6 c
Control	88.3 d	3.9 c	ND	ND	ND

Source: Adapted from Aldon, Cable and Scholl (1977).
Note: Column means followed by the same letter are not significantly different at the 5% level. ND = No data.

At the end of the first growing season the Spitter Emitter system had produced significantly better cover (Table 35.11), followed by the Submatic and Bi-Wall systems. The control plots had significantly lower plant density than all other plots. Average plant heights followed the same trend with smaller differences between systems.

Vegetation developed most rapidly on the Spitter Emitter plots because the full-circle spray completely covered the ground surface and irrigations were frequent enough to keep the surface moist. The Submatic emitters acted as point sources for water, and wetting of the surface depended on lateral movement of water in the soil a much slower process than direct application as a spray. Development of the vegetation cover was, therefore, slower and not as complete as on the Spitter plots. The Bi-Wall emitters projected a single-jet spray 0.5 to 0.7 m into the air. Because the spray was easily blown about, even by light breezes, it wetted the surface erratically, mostly within 30 cm or so. As a result, the vegetation cover was highly variable but concentrated mostly in bands less than 1 m wide along the irrigation lines.

In addition to the seeded grasses, annual forbs developed into an overstory approaching 100% cover on all Submatic and Spitter plots, and about 50% on the Bi-Wall plots by mid-August, apparently from seed present in the material spread on the dam face. Atriplex canescens seedlings were also present.

Erosion varied widely among irrigation methods, with the Spitter Emitter plots showing the greatest volume loss (Table 35.11). Erosion under Bi-Wall emitters was insignificant. The Submatic plots produced the most gullies (one below each emitter) but they were all small, averaging 3 cm deep. In contrast, the Spitter Emitter plots had fewer but much larger gullies. Gullies were up to 25 cm deep on the lower half of the Spitter Emitter plots.

From this study Aldon, Cable and Scholl (1977) concluded that steep-slope areas in a semi-desert environment could be revegetated with the aid of drip irrigation systems. The Submatic system used a reasonable amount of water (31 cm) to establish a good cover (256 plants/m^2) with a tolerable amount of soil loss (6 m^3/ha).

Considering labour costs only, the Submatic system had a cost advantage over the Spitter Emitter system, which required cutting the feeder lines and inserting the spray outlets. Submatic tubing could be ordered with emitters inserted. The Bi-Wall system cost less, but vegetation establishment was also poorer. However, in semi-arid areas 124 plants/m^2 may be all the climate will support.

35.3 OTHER GEOGRAPHIC REGIONS

May et al. (1971) used a sprinkler irrigation system to supply extra water for establishment of Agropyron intermedium, A. cristatum, Elymus junceus, Bromus inermis, and Trifolium hybridum broadcast seeded onto nine-year-old coal spoils near Kemmerer, Wyoming. Water from a nearby pit was applied at a rate of 5.1 cm/h with applications every four to six hours during a two-day period. Plots were irrigated in June and July.

By August of the first growing season, only a scattering of grass seedlings and small patches of T. hybridum were present on the plots. Volunteer species were abundant and seemed to have benefited from the added moisture. Salsola kali especially, showed a good response to irrigation. By the second season T. hybridum had produced the best stand of all species.

May et al. (1971) noted that the greatest problem with the irrigation trial was the erosion caused by poor absorption of the water. They noted that best response to irrigation was at the tops of the spoil banks where water had a chance to penetrate deeper than on the slopes.

35.4 SUMMARY

Irrigation must be considered a temporary measure with the objectives of: (1) enhancing germination; (2) establishing cover; (3) improving root growth; and (4) increasing soil moisture reserve. The literature indicates that these objectives are not always achieved.

Irrigation should be considered in light of local climate, regulations, availability and quality of water, and water requirements of plants. A general "rule of thumb" is that irrigation should be

considered only where the mine area receives less than 25 cm of precipitation. However, if water is plentiful this guideline may be revised upward.

Prior to irrigation, the mine spoil should be engineered to achieve maximum cost benefit from the operation. This may include improvement of infiltration, water retention, manipulation of topography, and erosion prevention measures.

Irrigation has not been studied extensively in mountain regions, probably because of practicality and need of operational application. One study noted that irrigation was of questionable value but did not completely dismiss it as a management practice. Irrigation was most useful when applied with a mulch; however, topsoiling was considered more beneficial.

Irrigation is of considerable importance in the plains, particularly in semi-desert regions. Results have varied considerably, however, and there are definitely species response differences and species x time of application interactions. Early (May) application of irrigation appears to favour agronomic species and favours cool season grasses over warm season grasses, thereby decreasing stand diversity. However, summer seeding with irrigation promotes the establishment of warm season perennial grasses in mixture with cool season grasses and also stimulates native grasses more than agronomics. Individual species within agronomic or native mixes as well as within warm or cool season mixes respond differently to season of seeding/irrigation combinations.

Most studies indicate that the first year of irrigation improves diversity and productivity while continued irrigation for two or three years increases productivity but possibly at the expense of diversity. Generally, temporary irrigation is recommended and late season (July to August) application is recommended over spring irrigation. Irrigation is certainly an excellent means of extending the seeding season.

The larger the volume of water applied, the greater the response of grasses and legumes, particularly in late summer. Where water quantity is limited, soil treatments may provide as much or more

benefit than irrigation. In any event, irrigation must be combined with spoil shaping to obtain maximum benefit.

Irrigation has reduced invasion by weed species by increasing the competitiveness of desirable species. This has been particularly noticeable in summer seeded plots.

Irrigation may have disadvantages. Top biomass may be increased to a far greater extent than root biomass. Roots tend to concentrate near the soil surface, particularly with frequent light applications of water, and this may leave plants susceptible to drought in very dry weather or when irrigation is removed. If irrigation is too intense or water droplets too large, erosion may be serious. In arid regions damage has occurred from animals seeking water.

Two types of irrigation (sprinkler and drip) are available. Advantages and disadvantages of each are given in Table 35.1.

Tests of three systems (Spitter Emitter (sprinkler), Submatic (drip) and Bi-wall (very limited spray)) indicated that the Spitter Emitter produced significantly better cover and plant height, followed by the Submatic and Bi-Wall, in that order. Cover increased more quickly with the Spitter Emitter because the total surface area is moistened. The Submatic produces very local cover and the Bi-Wall intermediate (bands) cover. Erosion loss was greatest using the Spitter Emitter (gullies up to 25 cm deep), small gullies were produced by the Submatic system, and erosion was insignificant with the Bi-Wall system. The Submatic was recommended because it used a reasonable amount of water to establish good cover with tolerable soil loss and also had a cost advantage over the Spitter Emitter. The Bi-Wall system was least expensive but vegetation establishment was poor. However, plant establishment resulting from this system may be the maximum that can be supported by the climate of semi-arid regions.

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36. FERTILIZERS FOR ESTABLISHMENT OF GRASSES AND FORBS

"The overburden disturbed by strip mining is variable in chemical properties within mine sites as well as among sites....Through the stripping process, stratified materials are mixed and, in general, inverted. With additional 'disturbance' occurring as a result of leveling, a given characteristic within the normal root zone can vary widely within a short distance, horizontally and vertically. One characteristic common to most spoils is the lack of organic matter and, hence, a major source of essential available nutrients for plant growth....

"In areal extent, the most widespread soil deficiencies occur with the macroelements N and P, which are deficient in soils varying widely in texture and organic matter content. Potassium deficiency occurs primarily in coarse- and moderately coarse-textured soils of low cation exchange capacity...." (Bauer, Berg and Gould 1978:451-452.)

Fertilizers may be applied to correct spoil nutrient deficiencies and enhance plant germination and yield. Species which respond primarily to nitrogen fertilization will be the vigourous herbaceous species, particularly annual weedy species and perennial grasses (Berg 1980). Phosphorus fertilization, on the other hand, improves growth of legumes.

As noted in DePuit and Coenenberg (1979:50-51), "...Meyn, Young and Holechek (1976) found that success of first year fertilization may be strongly affected by timing of application. In terms of N, which is quite mobile, fertilization is generally recommended as soon as seeded vegetation has become sufficiently established to exhibit growth responses to applied fertilizer, preferably immediately prior to or within a period of ample precipitation (i.e., middle to late spring in the Colstrip, [Montana] vicinity). Later fertilization in dry summer months may result in significant N loss through volatilization and/or lack of N uptake by plants due to their dormant condition. Fertilization far in advance of seeding may be similarly ineffective due to N losses through volatilization, leaching, and fixation processes. Finally, fertilization usually is not recommended at or immediately

following seedling germination, since plant germination and early growth may be inhibited by the osmotic (burning) effect of concentrated fertilizer salts at the soil surface. In terms of phosphorus, which is relatively immobile, certain of the above timing generalizations are less applicable - i.e., it is usually desirable to apply P as soon as possible after or even prior to seeding, to allow maximum time for P incorporation into the soil. However, since superior plant responses have in most cases been noted on mine spoils only when effective fertilization with both N and P has occurred, and N may be more easily lost through improper timing, the timing recommendations for N are usually advised when applications of N and P together are made."

Dean et al. (1973) noted that the addition of fertilizers may, however, inhibit seed germination and growth by:

1. increasing osmotic stresses around the seed through addition of salts;
2. releasing heavy metals through the action of fertilizer ammonia; and
3. species specific reactions to fertilizer. For example, legumes show declining germination with increased N-fertilization.

Efficiency of nutrient utilization will be greatest when fertilizer is applied at the time of greatest plant need and in a position suitable for uptake. Efficient application techniques will vary with factors affecting nutrient mobility in soil, and with plant and microbial immobilization rates, however, many predictable and unpredictable factors as well as logistics, preclude the utmost in precision (Bauer, Berg and Gould 1978; Sheard 1976).

Immobile nutrients, such as P, are limited to incorporation prior to seeding, or application during planting with suitable drill attachment equipment. If placed above the seed these nutrients are "positionally" unavailable because the emerging radicle grows downward. Actively growing plants with shallow roots can absorb immobile nutrients applied to the surface when the surface is moist.

Since positioning of mobile nutrients, such as NO_3-N, is less critical more application alternatives exist; they can be applied either before, during, or at planting. However, the high solubility of these nutrients can cause germination problems due to a "salt-effect", that is, a reduction in available water surrounding the seed. Plant species and available soil water content will determine the quantity of fertilizer that can be placed in contact with the seed without posing germination problems.

Annual applications of fertilizer result in more efficient utilization of both mobile and immobile nutrients than a single large application designed to meet crop needs for several seasons or a large application followed by maintenance rates. Reduction in efficiency when using a large dose may be attributed to time-dependent chemical chelation and biological immobilization processes or, in the case of mobile nutrients, to leaching.

The use of concentrated or slow-release fertilizers has provided some solutions to the problem of placing nutrients where and when plants require them, and reducing potential salt toxicity problems.

In addition to requiring less bulk per hectare for a given quantity of nutrients, concentrated (or pure) fertilizers also have a lower salt concentration per unit of available nutrients. For example, triple superphosphate (0-46-0) does not seriously inhibit germination even when seeds are in contact with it, whereas ordinary superphosphate (0-20-0), which is high in gypsum, causes serious retardation under moisture stress (Bengtson, Mays and Zarger 1971).

Slow-release fertilizers were developed to release to solution only a small quantity of the nutrient at a time, hopefully equal to the rate of uptake by the growing plant. This can be achieved by: (1) using chemical compounds having properties of slow breakdown or dissolution per se, or (2) by physically coating fertilizer pellets with semi-permeable membranes or inert materials (Sheard 1976).

36.1 NORTH-EAST (OIL SANDS) REGION

Rowell (1977, 1978, 1979) and Takyi et al. (1977) performed several experiments on the effects of fertilizer on plant establishment and growth in tailings sand at Fort McMurray, Alberta.

The site of the first series of experiments was the lower slope of the GCOS (now Suncor) tailings pond dike. The site is an east-facing 23 to 28° slope. The site had additions of peat incorporated 15 cm into the soil in the winter of 1970/71 was then hydroseeded at 33.6 kg/ha in May to a mix of Bromus inermis (33%), Agropyron cristatum (24%), Festuca rubra (15%), Melilotus sp. (14%), and Trifolium hybridum (14%). Both legumes were inoculated with commercial inoculants. The area was fertilized six times from May 1971 to July 1974 (see Takyi et al. 1977, and Table 36.1 for details).

In November 1974, a randomized block experiment was laid out to determine the type of fertilization program required after initial establishment of grass cover. Six fertilizer/lime combinations were tested in the first season's crop (see Table 36.1):

T0 = No fertilizer or lime (Nil)

T1 = 90 kg N, 23 kg P, 90 kg K and 9 kg S per hectare per year (NPKS)

T2 = Same as T_1 plus 11 t/ha of lime in the first year only (NPKS + lime)

T3 = 180 kg N, 46 kg P, 180 kg K and 18 kg S per hectare every other year ($N_2P_2K_2S_2$)

T4 = Same as T_3 plus 11 t/ha of lime in the first year only ($N_2P_2K_2S_2$ + lime)

T5 = G.C.O.S. 1975 fertilizer rates (41 kg N, 12 kg P, 22 kg K and 40 kg S per hectare in a split application in June and August

The following sources were used:

N = Ammonium nitrate and ammonium phosphate

P = Ammonium phosphate

K = Potassium sulphate and potassium chloride

S = Potassium sulphate

Table 36.1. Fertilizers added to a vegetated tailings sand dyke at the G.C.O.S. plant site at Fort McMurray between 1971 and 1977

	Treatment - Fertilizer Additions (kg/ha)											
	T0	T0A	T1	T1A	T2	T2A	T3	T3A	T4	T4A	T5	T5A
May 1971 to July 1974												
N	279	279	279	279	279	279	279	279	279	279	279	279
P	138	138	138	138	138	138	138	138	138	138	138	138
K	188	188	188	188	188	188	188	188	188	188	188	188
S	-	-	-	-	-	-	-	-	-	-	-	-
June 1975												
N	0	0	90	90	90	90	180	180	180	180	15	15
P	0	0	23	23	23	23	46	46	46	46	6	6
K	0	0	90	90	90[a]	90[a]	180	180	180	180[a]	11	11
S	0	0	9	9	9[a]	9[a]	18	18	18[a]	18[a]	14	14
August 1975												
N	0	90	0	90	0	90	0	180	0	180	26	76
P	0	0	0	0	0	0	0	0	0	0	6	6
K	0	0	0	0	0	0	0	0	0	0	11	11
S	0	9	0	9	0	9	0	18	0	18	26	26
June 1976												
N	0	0	90	90	90	90	0	0	0	0	43	43
P	0	0	23	23	23	23	0	0	0	0	11	11
K	0	0	90	90	90	90	0	0	0	0	22	22
S	0	0	0	0	0	0	0	0	0	0	9	9

continued

Table 36.1. Concluded.

	Treatment - Fertilizer Additions (kg/ha)											
	T0	T0A	T1	T1A	T2	T2A	T3	T3A	T4	T4A	T5	T5A
June 1977												
N	0	90	90	90	90	90	180	180	180	180	43	43
P	0	23	23	23	23	23	46	46	46	46	11	11
K	0	90	90	90	90	90	180	180	180	180	22	22
S	0	0	0	0	0	0	0	0	0	0	9	9
August 1977												
N	0	0	0	90	0	90	0	180	0	180	0	69
P	0	0	0	23	0	23	0	46	0	46	0	0
K	0	0	0	90	0	90	0	180	0	180	0	0
S	0	0	0	0	0	0	0	0	0	0	0	0
1978												
N	0	0	90	90	90	90	0	0	0	0	43	43
P	0	0	23	23	23	23	0	0	0	0	11	11
K	0	0	90	90	90	90	0	0	0	0	22	22
S	0	0	0	0	0	0	0	0	0	0	9	9

Source: Adapted from Rowell (1978, 1979:12-13)

Note: Fertilizers added as ammonium nitrate, ammonium sulfate, ammonium phosphate, potassium chloride and potassium sulfate.

a Lime added at 4.5 t/ha.

Lime = Finely ground agricultural lime

and for treatment T5

N = Ammonium sulphate and 6:24:24

P & K = 6:24:24

S = Ammonium sulphate

Plots were fertilized in June. The first harvest was on 17 August at which time yield data for B. inermis and F. rubra were taken. The old grass (pre-1975 growth) and new growth were separated. The authors did not statistically analyze yield data, and therefore discussions were limited to trends.

Fertilization improved yields of both species with the exception of B. inermis at Rate 5. The best response in both species resulted from the double fertilization rate (T3) without lime. Lime appeared to improve yield at the lower fertilizer rates but decreased it at the higher rates.

Field observations at the first harvest indicated apparent N deficiency symptoms in all treatments so the experimental plan was modified. All plots were sub-divided with half of the plots receiving additional N and S (see Table 36.1, these plots denoted by letter "A").

The second crop was harvested on 07 October from the previously harvested plots. The addition of extra N and S improved yields in all treatments (Table 36.2). The greatest yield of B. inermis came from the double fertilization plus extra N-S rate (T3A). Without the addition of extra N-S, B. inermis yields were very low in all plots. The greatest yield of F. rubra came from the single rate fertilizer plus lime and extra N-S (T2A). The addition of fertilizers improved yields 4 to 14 times over the controls; however, the plot which was fertilized only with extra N-S (T0A) had total yields similar to the more heavily fertilized plots.

A third harvest, made on 07 October in areas of the plots not previously harvested, showed the effects of the fertilization on an entire seasons' growth. The addition of fertilizer at any rate improved total yield 2.5 to 4 times over unfertilized plots (Table 20.3). The

Table 36.2. Dry matter yields of bromegrass and creeping red fescue regrowths as affected by fertilizer and lime treatments plus additional nitrogen and sulphur treatments on a vegetated GCOS tailings pond dike Fort McMurray, Alberta. — second harvest, (t/ha).

	Treatment	Bromegrass	Creeping Red Fescue	Bromegrass + C.R. Fescue
T0	Nil	0	0.09	0.09
T_0A[a]	Nil + NS	0.07	1.03	1.10
T_1	NPKS	0.02	0.40	0.43
T_1A	NPKS + NS	0.11	1.10	1.21
T_2	NPKS + Lime	0.02	0.29	0.31
T_2A	NPKS + Lime + NS	0.09	1.23	1.32
T_3	$N_2P_2K_2S_2$	0.05	0.49	0.54
T_3A	$N_2P_2K_2S_2 + N_2S_2$	0.34	0.85	1.19
T_4	$N_2P_2K_2S_2$ + Lime	0.05	0.54	0.58
T_4A	$N_2P_2K_2S_2$ + Lime ‡ N_2S_2	0.18	1.12	1.30
T_5	GCOS Rate (Spring & Summer)	0.02	0.56	0.58
T_5A	GCOS Rate (Spring & Summer) + N	0.05	1.08	1.12

Source: Adapted from Takyi et al. (1977).
[a] A = added NS

application of 90 kg N and 9 kg S (T0A) alone in mid-August provided nearly as much dry matter as the entire GCOS rate (T5).

Takyi et al. (1977) noted that while yields from the entire season harvest were smaller than the combined yields from two harvests, the risk of erosion losses due to removal of cover in the first harvest were minimized. They noted that vegetation can be maintained on the dike with minimum fertilizer additions of 90 kg N, 45 kg P, and 90 kg K per hectare but that a second application of extra N-S was more effective.

In the second season of the study, S was removed from treatments T1 and T2, and the entire GCOS rate was applied in June. Plots T0, T0A, T3, T3A, T4, and T4A were not fertilized at all (Table 36.1). Plant productivity was assessed in June and September, giving a measure of early productivity and annual productivity.

Plots which had been fertilized in late August of the previous year had greater early growth (Table 36.3) than those not so fertilized. This is important as early growth provides a good initial cover for erosion protection. The highest yield was on the plots which had received the double rate plus extra N-S the year before (T3A), followed by the plots which had received the double rate plus lime and extra N-S (T4A).

Differences between treatments were less evident when total yields for the growing season were examined (Table 36.3). The plots that received fertilizer in 1976 (T1, T1A, T2, T2A, T5, T5A) produced greater annual yields than those fertilized only in 1975 or those not fertilized at all. The early growth up to June on the double rate fertilized plots tapered off by September. The greatest yield came from the plots receiving the single application GCOS rate (T5A).

In the third growing season plots were again fertilized (see Table 36.1 for rates) in June and August. Dry-weight measurements were taken in June and August. Data on percent cover of the species in each plot were also taken in August.

The changes in plant species composition on the plots had developed into a trend by the third growing season. The plots which had

Table 36.3. Dry-weight yield (kg/m^2) of plant tops in June and September of the second growing season, Fort McMurray, Alberta.

Treatment	Mean plant top yield (kg/m^2)	
	June	September
T_0	0.054	0.239
T_0A	0.085	0.324
T_1	0.077	0.376
T_1A	0.121	0.371
T_2	0.084	0.386
T_2A	0.113	0.364
T_3	0.100	0.260
T_3A	0.170	0.291
T_4	0.095	0.322
T_4A	0.166	0.304
T_5	0.081	0.376
T_5A	0.133	0.403
L.S.D.	0.061	0.073

Source: Adapted from Rowell (1977).

received frequent fertilizer applications (T1A, T2A, T3A, and T4A) had almost pure stands of Bromus inermis (Table 36.4) while the unfertilized areas (T0) or those which had received low rates (T0A, T5) were dominated by Festuca rubra. Where plots had received intermediate levels of fertilizer, B. inermis was replacing F. rubra.

Rowell (1978) noted that this change may be significant in that Festuca, which builds up a thick litter mat, may help in conserving soil moisture losses but also provides an excellent habitat for rodents. Bromus, on the other hand, has a high leaf surface area and a greater potential dry matter production than Festuca, but is liable to high moisture uptake and transpiration losses.

Early growth and productivity in June of the third year was considerably lower than in the previous year (Table 36.5), especially in the unfertilized plots. The greatest yield was again in the plots fertilized with double rates (T3A). Yields were 1.5 to 4.5 times greater on fertilized plots than on unfertilized plots. By September, yields were still lower than those of the previous year, with the exception of plots T3 and T3A. The "A" plots had higher yields than the other plots with the exception of Treatment 3. Addition of fertilizers increased yields 3.5 to 6 times.

Fertilization was done only in June of the fourth growing season (see Table 36.1 for rates). By the end of the fourth growing season all but three plots were dominated by Bromus (Table 36.6). The three exceptions were the control plots (T0, 5% Bromus), the control plots with extra N-S (T0A, 45% Bromus) and the GCOS rate plots without extra N-S (T5, 33% Bromus). Trifolium hybridum had become more important in successive years in the control plots (0, 3, 11, and 23% cover in the past four seasons).

Plant yields were assessed in September. Yields were equal to or better than those from the second season (Table 36.6). The addition of fertilizers increased yields 1.5 to 4 times over controls. The greatest yield was obtained on the plots receiving the normal fertilizer rate plus lime and additonal N-S (T2A). Plots that had received extra

Table 36.4. Distribution of plant species on experimental plots on a vegetated tailings sand dike at Fort McMurray, Alberta.

Treatment	Percentage Cover			
	1976		1977	
	Creeping Red Fescue	Bromegrass	Creeping Red Fescue	Bromegrass
T_0	88	9	88	1
T_0A	79	18	71	27
T_1	66	33	20	80
T_1A	42	58	7	93
T_2	50	50	23	77
T_2A	45	55	8	92
T_3	80	20	17	83
T_3A	30	70	3	97
T_4	69	25	32	67
T_4A	52	45	8	91
T_5	80	19	74	24
T_5A	71	28	53	47

Source: Adapted from Rowell (1978).

Table 36.5. Dry-weight yield of plant tops in June and September, 1977, on a vegetated tailing sand dike at Fort McMurray, Alberta.

	Mean yield of Plant Tops (kg/m^2)	
Treatment	June	September
T_0	0.027	0.054
T_0A	0.041	0.197
T_1	0.093	0.245
T_1A	0.114	0.272
T_2	0.091	0.259
T_2A	0.081	0.308
T_3	0.027	0.343
T_3A	0.126	0.275
T_4	0.049	0.271
T_4A	0.101	0.317
T_5	0.070	0.165
T_5A	0.086	0.267
L.S.D.	0.063	0.078

Source: Adapted from Rowell (1978).

Table 36.6. Species composition (%) and dry matter yields (kg/m^2) of plant tops under various fertilizer treatments on a vegetated tailing sand dike at Fort McMurray, Alberta.

Treatment	Yield (kg/m^2)	Brome cover	Fescue cover
T_0	0.145[a]	5	72
T_0A	0.313	45	47
T_1	0.518	98	2
T_1A	0.555	98	2
T_2	0.434	99	1
T_2A	0.588	99	1
T_3	0.436	96	3
T_3A	0.449	100	0
T_4	0.367	88	10
T_4A	0.436	97	1
T_5	0.194	33	58
T_5A	0.445	80	20

Source: Adapted from Rowell (1979).

[a] L.S.D. = 0.105

N-S in August of the previous season had greater yields than the plots without the extra N-S.

From this study the authors concluded that:

1. Early plant growth and erosion control was related to the extent of previous fertilization, especially late season fertilizer applications.
2. Best cover comes from minimum application of 90 kg N, 23 kg P, and 90 kg K per hectare. Applying double the rate every two years was less effective than applying the lower GCOS rate.
3. Fertilization increased the cover of Bromus inermis over Festuca rubra. Legumes were virtually absent from fertilized plots.

In a second series of experiments nutrient levels and substrate were varied and the response of vegetation was studied. Takyi et al. (1977) examined the effects of four nutrient levels on two grass/legume mixtures sown on five surface amendments in a controlled growth chamber experiment.

The five substrates were:

1. tailings sand (1600 g per pot);
2. tailings sand (840 g) + GCOS peat (160 g) mixed in an approximate ratio of 1:1 by volume, per pot;
3. tailings sand (850 g) + GCOS overburden (750 g) mixed in an approximate ratio of 1:1 by volume, per pot;
4. tailings sand (1050 g) + GCOS peat (80 g) + GCOS overburden (470 g) mixed in an approximate ratio of 2:1:1 by volume, per pot; and
5. agricultural soil (Malmo, 1200 g per pot).

The four fertility levels were:

1. nil (no fertilizers or lime);
2. NPKS -- 112 kg N, 56 kg P, 132 kg K, and 25 kg S per hectare;
3. NPKS plus micro-elements; and
4. NPKS plus micro-elements plus lime (13.5 t/ha).

The grass-legume mixtures used were:

1. Bromus inermis + Medicago sativa; and
2. Agropyron trachycaulum + Onobrychis sp.

Each pot was sown with the same number of legume and grass seeds, and was thinned one month after germination to three plants of each species. Two crops were grown: (1) 24 January to 16 May and (2) 29 May to 27 September. Data on yields of grass and legume tops and roots were obtained.

In both seedings the NPKS treatment gave a substantial yield increase over the controls (Table 36.7). The addition of micro-elements improved yield only on the tailings sand and the tailings sand/overburden mix. Lime improved yields in the tailings sand/peat mix only. Takyi et al. (1977) felt that the low yields in this mix without lime were due to the low pH. In both seedings the percentage of grasses was higher in fertilized pots than in unfertilized pots.

They concluded that the addition of NPKS was far more important than additions of micro-elements or lime in establishing plants on amended tailings sands.

Rowell (1977, 1978, 1979) studied the effects of three fertilization levels on a grass/legume mix sown on eight surface amendment plots on new tailings slopes.

The three fertilization treatments were:

1. 80 kg N/ha (23.3 kg/ha NO_3 N, 56.7 kg/ha NH_4 N)
   35 kg P/ha
   75 kg K/ha
   20 kg S/ha
   Applied in June as 21-0-0, 34-0-0, 11-55-0 and 0-0-62
2. 150 kg ha/N (58.3 kg/ha NO_3 N, 91.7 kg/ha NH_4 N)
   40 kg P/ha
   150 kg K/ha
   20 kg S/ha
   Applied in June as above.
   Lime 5 t/ha

Table 36.7. Dry matter yields of grass-legume mixtures grown on different soil mixes as affected by fertilizer and lime. First seeding.[a]

	Yield (g/pot) average of two replicates											
	Tops				Roots				Tops + Roots			
	Nil	NPKS	NPKS + Micro	NPKS + Micro + Lime	Nil	NPKS	NPKS + Micro	NPKS + Micro + Lime	Nil	NPKS	NPKS + Micro	NPKS + Micro + Lime
Tailings Sand	0.15	2.07	2.57	0.57	0.26	1.82	2.41	0.30	0.41	3.89	4.97	0.87
Tailings - Sand:Peat (1:1)	0.22	1.91	1.72	2.65	0.43	1.63	1.13	1.80	0.69	3.59	2.85	4.45
Tailings - Sand:Over-burden (1:1)	0.21	1.43	2.16	2.03	0.30	0.95	1.45	1.92	0.51	2.37	3.60	3.95
Tailings - Sand:Peat: Overburden (2:1:1)	0.21	2.41	2.36	2.31	0.38	1.71	1.44	1.71	0.58	4.11	3.80	4.02
Agricultural Soil (Ha...ao)[b]	2.12	4.22	4.24	4.51	1.36	1.82	2.33	1.63	3.53	6.04	6.57	6.14

Source: Takyi et al. (1977:131)

a Yields showed similar trends for the second seeding.

b A high percentage of the fine roots in the Ha!mo could not be recovered.

3. Fertilizer mix as described for 2; applied in June and August with no lime added in August.

The eight surface amendments were:

1. peat tilled to a depth of 15 cm;
2. peat tilled to a depth of 15 cm with contour trenches constructed across the plot;
3. peat tilled to a depth of 15 cm with Aquatain soil stabilizer added to the soil surface;
4. peat tilled to a depth of 15 cm with Bitumuls soil stabilizer added to soil surface;
5. overburden added at a rate of 750 t/ha (about 5 cm) onto the surface of applied peat;
6. overburden added at a rate of 1500 t/ha (about 10 cm) tilled into the surface 15 cm of peat and tailings sand;
7. overburden added at a rate of 750 t/ha tilled into the surface 15 cm of peat and tailings sand; and
8. peat tilled into a depth of 15 cm (i.e., as Treatment 1) but not seeded until October 1976.

Lime was added by manual spreading and fertilizer was broadcast in late June. Plots were then raked lightly to incorporate fertilizer and lime 5 to 8 cm into the soil. The seed mix and seeding rates used are shown in Table 33.7. Data on plant productivity were taken for three seasons.

In the first season, Avena sativa accounted for 85 to 93% of the dry matter produced on the plots. Mean yields (all surface amendments combined) were slightly higher for fertilizer Treatment 1 in the first season; however, response on the individual plots was highly variable (Table 36.8). By the second season the growth of plants under fertilizer Regime 3 was significantly higher than those under Regime 1. This result was consistent for all the substrates tested. In addition, results of an early June cropping showed higher yields under fertilizer Regime 3, probably due to the extra nutrients provided by the second addition of fertilizer in August. Plant yield in the third season was again greatest in plots receiving the most fertilizer.

Table 36.8. Dry matter production of plant tops over a three year period as affected by fertilizer treatments, Fort McMurray, Alberta.

Fertilizer	Substrate								Mean
	1	2	3	4	5	6	7	8	
First Season Yield (kg/m^2)									
1	0.293	0.220	0.284	0.261	0.341	0.393	0.326	ND	0.345
2	0.300	0.147	0.185	0.358	0.369	0.318	0.259	ND	0.276
3	0.304	0.263	0.195	0.301	0.343	0.361	0.246	ND	0.287
Second Season Yield (kg/m^2)									
1	0.268	0.282	0.268	0.282	0.283	0.265	0.259	0.204	0.263
2	0.303	0.267	0.326	0.378	0.415	0.336	0.362	0.264	0.331
3	0.393	0.438	0.433	0.449	0.435	0.423	0.426	0.235	0.404
Third Season Yield (kg/m^2)									
1	0.143	0.174	0.167	0.171	0.170	0.160	0.136	0.174	0.161
2	0.351	0.258	0.232	0.291	0.278	0.295	0.269	0.350	0.290
3	0.394	0.321	0.394	0.393	0.371	0.385	0.397	0.395	0.381

Source: Adapted from Rowell (1977a, 1978, 1979).

By the third growing season a pattern had emerged showing a change in species cover with fertilization. On the plots receiving increasing levels of fertilizer, Bromus inermis became a dominant species (Table 36.9). As mentioned in the discussion of the previous experiment this could have significant effects on future reclamation success.

The conclusions from this study were similar to those from the previous study: (1) a low level of fertilizers can establish adequate cover, (2) late application of fertilizer provides for rapid spring growth, and (3) increased production comes with higher fertilizer applications, as does a change in species composition to a Bromus dominated system. In addition to these conclusions Rowell noted that active nutrient cycling appeared to start earlier in the plots which had received high initial fertilizer inputs.

Several studies in Great Britain on reclamation of china clay wastes and flourspar tailings have relevance to the Oil Sands region as these substrates have many properties in common with tailings sand.

Handley et al. (1978) and Bradshaw et al. (1975) discussed the effects of fertilizers on the establishment of grass/legume mixtures on china clay wastes in England. In early hydroseeding trials, grass stands were established without difficulty on waste sand materials but rapid deterioration occurred unless fertilizer was applied. Several combinations of fertilizers were tested on these failing stands and results indicated that N was the limiting factor to plant growth.

In a greenhouse experiment a mixture of Festuca rubra cv. S59 and Trifolium repens cv. Kent Wild was sown onto sand waste supplemented with various fertilizer combinations. The basic treatment received 50 kg/ha N, 22 kg/ha P, and 41.5 kg/ha K. This rate of application was doubled; for each macronutrient in turn in the additional treatments. Initially, the high N treatment gave the best yield of plant material but during the second season, without additional fertilizer, this was the lowest yielding treatment. Regrowth during the second year was very much a function of the performance of T. repens. In the high N

Table 36.9. Assessment of percentage ground cover by seeded grass and legume species in 1977 and 1978, Fort McMurray, Alberta.

Species	Fertilizer Treatment (% mean[a])					
	A		B		C	
	1977	1978	1977	1978	1977	1978
Brome Grass	34	36	47	81	62	99
Wheat Grasses (Streambank, Pubescent, Slender)	51	26	38	9	31	1
Blue Grasses (Canada, Kentucky)	8	22	9	6	4	1
Hard Fescue	6	7	4	4	1	1
Cicer Milk Vetch	6	1	1	0	1	0
Alfalfa	3	5	1	1	0	0

Source: Adapted from Rowell (1979).
Note: Approximate Cover 1976: Pendek Oats -- 88.7% by weight, grasses -- 9.7%, legumes -- 1.6%.
[a] Mean of Treatments 1, 5, 6 and 7.

treatment, T. repens establishment was suppressed but in the high P regime, establishment and growth of T. repens was encouraged.

Using a more complex grass/clover mixture a similar experiment was carried out under field conditions. The experiment involved a factorial design with four lime levels and five fertilizer treatments:

1. Basic NPK 50 kg/ha N; 22 kg/ha P; 41.5 kg/ha K
2. Basic NPK + 50 kg/ha N initially as NH_4NO_3
3. Basic NPK + 50 kg/ha N after three months as NH_4NO_3
4. Basic NPK + 50 kg/ha N as sulphur coated urea (Gold N)
5. Basic NPK + 22 kg/ha N as NH_4MgPO_4 (Enmag)

The experiment was set up in April 1972 and harvested in August 1973. The yield was doubled (significant at P .05) by increasing the initial nitrogen three months after establishment. However, the legume component was heavily suppressed in these treatments and prospects for regrowth were poor. The highest yield (significant at P .05) was obtained with additional phosphate which supported a vigourous growth of T. repens during the second season. Sulphur coated urea, a controlled release fertilizer formulated to give nitrogen release over a 180-day period, had no special advantage over ammonium nitrate at this rate of application.

Handley et al. (1978) compared the response of a grass mixture (Lolium perenne, Agrostis tenuis, Festuca rubra) to fertilizer nitrogen, supplied at 100 kg/ha from various sources. In both seasons, ammonium sulphate provided the best growth (Table 36.10) while urea formaldehyde, dried blood, and hoof and horn gave the worst results. They noted that the extensive leaching in the sandy soil resulted in the ammonium nitrogen fertilizers performing better than the nitrate nitrogen fertilizers.

Johnson (1976) studied the effects of all combinations of N, P, and K on growth of a grass/legume mixture sown on fluorspar tailings in Great Britain. The tailings had a particle size equivalent to fine sand and silt and were low in N, P, and organic matter. In the spring of 1973, a series of 0.84 m^2 trial plots were established on a recently

Table 36.10. Response of a grass sward on sand waste to nitrogen fertilizers applied at 100 kg/ha N. Data presented as shoot dry matter in g/m.

Treatment	First year	Second year
Ammonium sulphate	94 a	262 a
Ammonium nitrate	63 b	168 ab
Sodium nitrate	1	216 a
Sulphur coated urea	21 c	68 bc
Ureaformaldehyde	2 d	13 c
Dried Blood	7 d	33 c
Hoof and Horn	11 d	43 c

Source: Handley et al. (1978).
Note: Treatment means sharing the same letter are not significantly different at 5% probability.

abandoned and uncolonized tailings pond. A 5:4:1 mixture of Lolium perenne, Festuca rubra, and Trifolium repens (inoculated seed) was sown on each plot at a rate of 78.4 kg/ha. Using a factorial design, with each treatment replicated three times, the effects of adding nitrogen (as nitrate of soda), phosphorus (as superphosphate), and potassium (as potassium sulphate) on yield were observed. The nutrients were applied at a rate equivalent to 100.8 kg/ha of the individual elements.

Plant yield data, collected in the fall of the first growing season, indicated that plants responded significantly to inputs of N and P but not to K. When applied alone, N had a greater effect than did P. The addition of NP or NPK produced the best yields in the trial.

The species composition of the plots varied according to the fertilizer treatments. Lolium dominated all plots to which nitrogen was applied, regardless of the phosphorus and potassium treatments. Trifolium established, but grew poorly as a result of competition. A balance between the grasses and clover was more apparent where phosphorus was applied in the absence of nitrogen. Growth was poor initially, but Trifolium established successfully and subsequently grew vigorously. Most plants had effectively nodulated root systems.

Johnson noted that growth on plots without legumes was poor in the second growing season due to rapid leaching of nutrients in the sandy tailings. He also noted that concentrations of fluoride, lead, and zinc in the plant tissues were much higher than those in natural areas, rendering the plants unsuitable for grazing.

36.2 MOUNTAINS AND FOOTHILLS REGIONS

Macyk examined the effects of fertilizer additions from 1972 to 1978 on agronomic grass/legume mixtures sown on coal spoils at the McIntyre #8 Mine in Grande Cache, Alberta (elevation = 1615 m) (Macyk 1972, 1973, 1974, 1975, 1976, 1977, 1978).

In the spring of 1972 two test sites at the mine were selected and plots laid out. In Area I, seven seed mixes (1 to 5, 7, 8;

Table 36.11) were tested with and without fertilizer. In Area II, seven seed mixes (1 to 7; Table 36.11) were tested as well. Seeding and fertilization were done at the end of May using a push-type cyclone spreader. Plots were then hand raked to incorporate the seed into the soil. Three fertilizers were applied to the appropriate 9.6 x 6.1 m subplots: (1) 4.5 kg of 34-0-0; (2) 4.5 kg of 11-48-0; and (3) 3.6 kg of 0-0-60. These applications resulted in 2.0 kg N, 2.2 kg P, and 2.2 kg K on each 58.6 m^2 plot.

By the end of June there were no visual differences in growth between fertilized and unfertilized plots. However, by the end of August the fertilized plots exhibited a much better yield (Table 36.12). Preliminary recommendations from this study were that fertilizers would be required to establish grass/legume mixes on these spoils.

In the second growing season (1973) Macyk subdivided each plot in Area I and applied fertilizer in May to one half of each plot. Plots that were fertilized in 1972 received an equivalent of 78.5 kg/ha of 27-14-0. Plots not fertilized in 1972 received an equivalent of 39.2 kg/ha of 27-14-0. In Area II, some of the unfertilized, and all of the fertilized plots were split. Half of each received an equivalent of 39.2 kg/ha of 27-14-0.

Plots that received fertilizer in both 1972 and 1973 showed better vigour and growth than those not fertilized in 1973. Similarily, those plots fertilized in 1973, but not in 1972, showed better vigour than those not fertilized at all. Yields decreased in the following order: (1) fertilized 1972, 1973; (2) fertilized 1972, (3) fertilized 1973, and (4) not fertilized (Table 36.13).

In the third growing season (1974) selected plots in Areas I and II were further subdivided (Figure 36.1) to provide a variety of fertilizer/year combinations. Macyk noted that the effects of fertilization were more pronounced in this season than previously. The plots that received fertilizer only in 1972 were dry and brown, with little growth. Nitrogen deficiency was evident in plots fertilized in 1972 and 1973 but not in those fertilized in 1974. The plots fertilized

Table 36.11. Seed mixtures and seeding rates used in fertilizer study, Grande Cache, Alberta.

Mixture #	Species	Seeding Rate (kg/ha)
1	Birdsfoot trefoil (Leo)	7.9
2	Alfalfa (Roamer)	5.6
	Crested Wheatgrass (Fairway)	28.0
3	Alfalfa (Rambler)	5.6
	Russian Wildrye (Sawki)	28.0
4	Alfalfa (Roamer)	5.6
	Creeping Red Fescue	16.8
	Bromegrass (Carlton)	16.8
5	Sweetclover	11.2
	Bromegrass (Magna)	16.8
	Crested Wheatgrass (Nordan)	16.8
6	Creeping Red Fescue	13.5
	Kentucky Bluegrass	9.0
	Alsike Clover	11.2
	Redtop	11.2
7	Creeping Red Fescue	13.5
	Kentucky Bluegrass	9.0
	Spring Vetch	11.2
	Timothy	11.2
8	Sweetclover	3.4
	Alsike Clover	3.4
	Creeping Red Fescue (Boreal)	6.7
	White Clover	3.4
	Bromegrass (Magna)	11.2

Source: Adapted from Macyk (1972).

Table 36.12. Forage dry matter yields (kg/m^2) as affected by fertilizer treatments, Grande Cache, Alberta.

Seed Mix	Area I		Area II	
	Fertilized	Control	Fertilized	Control
1	0.15	NDc	0.04	ND[c]
2	0.23	0.02	0.18	0.01
3	ND[a]	ND[c]	0.10	0.004
4	0.15	0.01	0.12	ND[c]
5	0.25	0.02	0.12	0.02
6	no plot		ND[c]	ND[b]
7	0.18	ND[a]	0.12	0.01
8	0.08	ND[b]	no plot	

Source: Adapted from Macyk (1972).

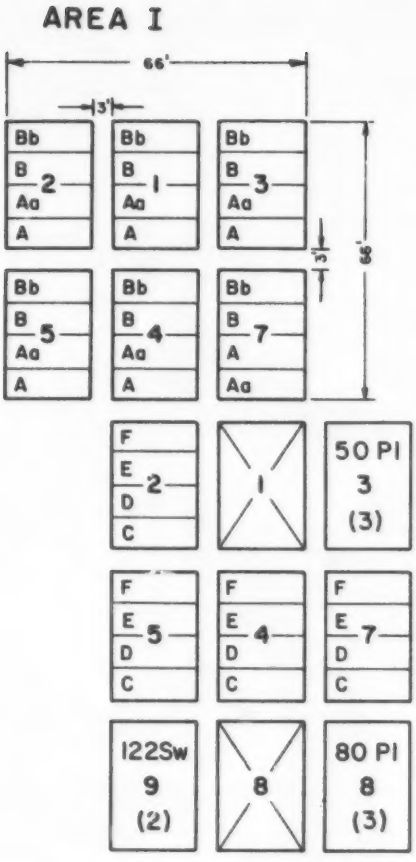
[a] Not sampled due to plot collapse
[b] Not sampled due to grazing disturbance
[c] Not sampled due to low growth of grasses (2.5 to 3.8 cm)

Table 36.13. Dry matter yields (kg/m^2) as affected by fertilization, Grande Cache, Alberta.

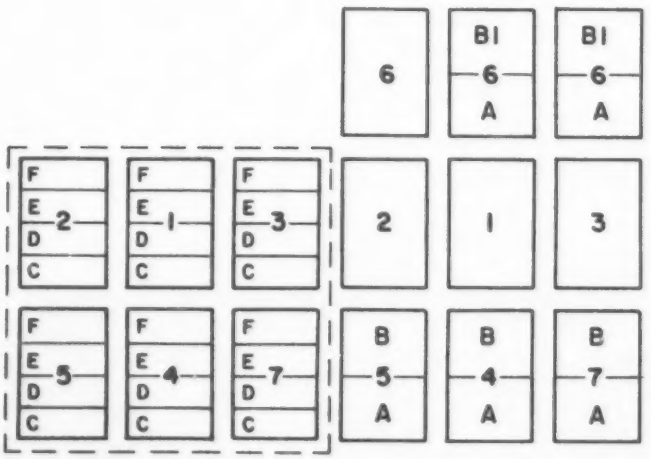
Seed mix and Treatment	Area I		Seed mix and Treatment	Area II	
	Fertilized 1973	Not Fertilized 1973		Fertilized 1973	Not Fertilized 1973
2F[a]	0.59	0.23		0.74	0.39
4F	0.92	0.49		0.63	0.37
5F	0.92	0.52		0.70	0.51
7F	0.83	0.70		0.79	0.50
3F	--	--		0.43	0.22
2NF	0.18	0.09	7NF	0.35	0.18
4NF	0.22	0.12	--	--	--
5NF	0.20	0.07	--	--	--

Source: Adapted from Macyk (1973).

[a] F = Fertilized in 1972 NF = Not Fertilized in 1972



FERTILIZER TREATMENTS			
	1972	1973	1974
A			x
Aa			
B		x	
Bb		x	x
C	x		x
D	x		
E	x	x	
F	x	x	x



FERTILIZER APPLICATIONS (x)			
	1972	1973	1974
A			
B		x	
Bl	x	x	
C	x		x
D	x		
E	x	x	
F	x	x	x

Figure 36.1. Fertilizer treatments studied at Grande Cache, Alberta

Source: Macyk (1974a)

in 1972 and 1974 appeared to be doing as well as those fertilized in all three years. Table 36.14 shows dry matter yields from selected, representative plots in Areas I and II.

Macyk (1974) noted that unlike legumes, grasses responded positively to fertilization. The density of Medicago sativa was greatest in plots that had not received maintenance fertilizers, while grasses were more vigourous in plots that had received fertilizer each year.

In the fourth growing season (1975) several plots were again subdivided and fertilizer applied at a rate equivalent to 112.1 kg/ha of 28-14-0 (Figure 36.2). As in the previous season the plots that had not received fertilizer since 1972 had very little green growth. Yields for one representative set of plots from Area II are shown in Table 36.15. The data indicated that those plot segments fertilized in 1975 produced almost twice the dry matter as those not fertilized in 1975. It also showed that segments fertilized three times in the last four-year period were producing as well as those segments fertilized in each of the four years.

Macyk continued to fertilize and evaluate plots for three more years, however no data were presented in his reports (Macyk 1976, 1977, 1978).

Macyk (1972, 1973, 1974) also assessed various fertilizer combinations on growth and yield of two grass/legume mixtures on topsoiled coal spoils at Grande Cache.

The two seed mixtures used were:

1. Festuca rubra (22.4 kg/ha), Phleum pratense cv. Climax (5.6 kg/ha), Agropyron cristatum cv. Nordan (22.4 kg/ha), and Medicago sativa cv. Rambler (5.6 kg/ha).
2. Agropyron cristatum cv. Fairway (16.8 kg/ha), Agrostis stolonifera (9 kg/ha), Bromus sp. cv. Carlton (16.8 kg/ha), and Trifolium hybridum (13.5 kg/ha).

Plots were seeded in August. Fertilizers were applied with a rotary spreader during the fall of the first season and spring of

Table 36.14. Dry matter yields (kg/m^2) for two seed mixes sown on Areas I and II as affected by fertilization, Grande Cache, Alberta.

Seed Mix	Area I Fertilizer Applied			Area II Fertilizer Applied			Yield	
	1972	1973	1974	1972	1973	1974	Area I	Area II
2	X			X			0.18	0.51
	X	X		X	X		0.80	0.75
	X		X	X		X	0.95	0.95
	X	X	X	X	X	X	0.99	1.38
5	X			X			0.59	0.78
	X	X		X	X		1.02	1.10
	X		X	X		X	1.12	1.11
	X	X	X	X	X	X	1.21	1.32

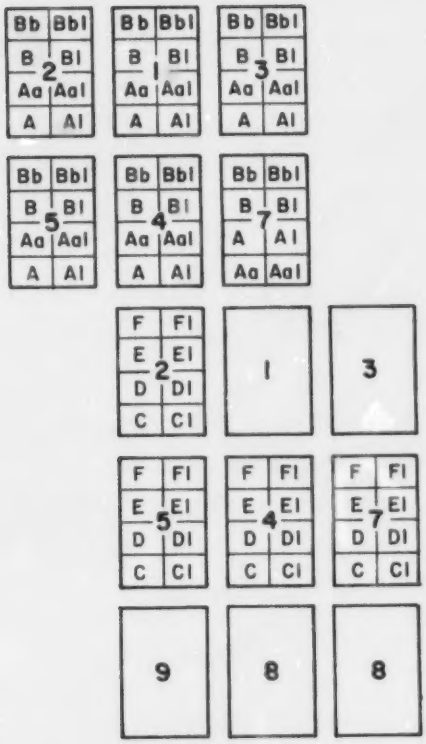
Source: Adapted from Macyk (1974).

Table 36.15. Forage yields from Seed Mix No. 2 in Area II as affected by fertilization, Grande Cache, Alberta.

Years Fertilized				Yield
1972	1973	1974	1975	(kg/m^2)
X				0.05
X				0.05
X	X			0.19
X		X		0.53
X	X	X		0.49
X	X		X	0.92
X		X	X	0.97
X	X	X	X	0.92

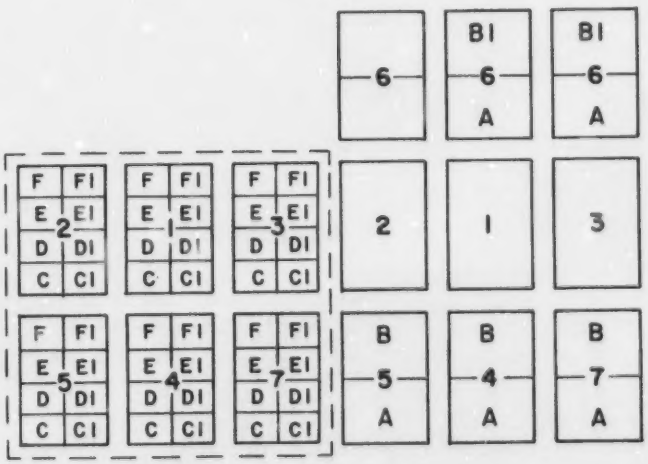
Source: Adapted from Macyk (1975).

AREA I



FERTILIZER TREATMENTS FOR SELECTED PLOTS IN AREA I				
	1972	1973	1974	1975
A			x	x
Al			x	
Aa				
Aal				
B		x		x
Bl		x		
Bb		x	x	x
Bbl		x	x	
C	x		x	x
Cl	x		x	
D	x			
Dl	x			
E	x	x		x
El	x	x		
F	x	x	x	x
Fl	x	x	x	

AREA II



FERTILIZER APPLICATIONS (x)				
	1972	1973	1974	1975
A				
B		x		
Bl	x	x		
C	x		x	x
D	x			
E	x	x		x
F	x	x	x	x
Cl	x		x	
Dl	x			
El	x	x		
Fl	x	x	x	

Figure 36.2. 1975 fertilizer applications for the Grande Cache, Alberta study site.

Source: Macyk (1975)

the second season. Treatments were different for the two mixes (Table 36.16). In the spring of the third season, one half of each plot was fertilized to assess the effects of removal of fertilizers. Data on dry matter production were taken in the second and third seasons. No statistical analyses were performed.

In the second season, yield of Mix #1 was improved by fertilizer Level C but lowered somewhat by Level B (Table 36.17). Yield of Mix #2 was improved with the addition of extra fertilizer.

In the third season, the plot halves which received fertilizer had greater yields in both mixes than those not fertilized (Table 36.17). Highest yields for Mix #1 were found with fertilizer Level B, which had the lowest yield the previous season. The increased level of fertilization produced slightly more dry matter in Mix #2.

At Cadomin, Alberta (elevation = 1675 m), Takyi and Russell (1980) and Russell and Takyi (1979) studied the effects of fertilization, seeding rate, companion crop, and topsoiling on a native species seed mix and an agronomic mix.

The agronomic species mix trial was established on raw coal overburden material and on overburden top-dressed with 20 cm of mineral soil. The seeding and fertilizer rates are shown in Table 36.18. The agronomic seed mixture was composed of Festuca rubra (40% by weight), Trifolium repens (12%), Phleum pratense cv. Climax (24%), and Poa compressa cv. Canon (24%). All legume seed was dry mixed with the proper commercial inoculant just prior to sowing.

The native species mix trials were also established on raw overburden and top-dressed plots. The seed mix was composed of equal numbers of seeds of Agropyron trachycaulum (69% by weight), Festuca saximontana (15%), Poa interior (8%), and Trisetum spicatum (8%). The fertilizer rates are shown in Table 36.20.

Plots were assessed for cover each September for two growing seasons. Fertilizer N was supplied as urea and 10-30-10, the source of P was 10-30-10, and of K was 10-30-10 and KCl. Plots were fertilized in June at seeding time.

Table 36.16. Fertilizer treatments tested on two seed mixes at Grande Cache, Alberta.

Mix	Treatment	Fertilizers N-P-K (kg/ha)		
		34-0-0	11-48-0	0-0-60
1	A	2.2	2.2	2.8
	B	3.4	3.4	2.2
	C	5.6	5.6	2.2
2	A	3.4	3.4	2.2
	B	5.6	5.6	2.2

Source: Adapted from Macyk (1972).

Table 36.17. Response of two seed mixes to various fertilizer regimes at Grande Cache, Alberta.

Seed Mix	Treatment	Production (kg/m^2)		
		Second Season	Third Season[a]	
			F	NF
1	A	0.32	0.99	0.96
	B	0.27	1.32	0.88
	C	0.43	1.04	0.89
2	A	0.34	1.31	0.98
	B	0.38	1.42	0.91

Source: Adapted from Macyk (1973, 1974).

[a] Third season results are for fertilized half-plots (F) and unfertilized half-plots (NF).

Table 36.18. Effects of varying the seeding and fertilizer rates on the plant cover produced by an agronomic grass/legume seed mixture grown on raw overburden and top-dressed spoils, Cadomin, Alberta.

	Fertilizer Rates (kg/ha) N-P-K[a]				
	0-0-0	40-20-40	60-30-60	80-40-80	80-40-80[b]
First season ground cover (%)[c d]					
Raw Spoil	1.6 c	21.4 b	28.0 b	29.3 b	45.1 a
Topdressed Spoil	3.7 b	10.0 a	11.6 a	14.0 a	10.5 a
Second season ground cover (%)					
Raw Spoil	1.0 a	49.3 b	71.7 bc	81.3 c	76.4 c
Topdressed Spoil	9.5 a	43.8 b	55.0 b	62.3 b	60.2 b

Source: Adapted from Takyi and Russel (1980) and Russell and Takyi (1979).

a Second season rates reduced to 40-17-20, 60-26-30, and 80-35-40.
b Split application; 40-20-40 applied on 21 June and again on 3 August.
c Average value based on three reps and four seeding rates.
d Means followed by the same letter within a given row are not significantly different at the 5% level according to Duncan's New Multiple Range Test.

In the first and second season, cover of the agronomic species was significantly improved by the addition of fertilizer on both raw spoils and top-dressed plots (Table 36.18). There were no significant differences between fertilizers on the topsoiled plots. The split application of fertilizer produced significantly more cover on raw spoils in the first season but no added benefit occurred from the split application in year two. Also, in the second season the 40-20-40 fertilizer produced significantly less cover than the two 80-40-80 treatments on raw spoils. Fertilizers also increased species frequency on both media.

Second season dry matter production was significantly increased by the addition of the 60-30-60 (kg/ha N-P-K) and 80-40-80 fertilizers on raw spoil and by the 80-40-80 rate on top-dressed plots (Table 36.19). The split fertilizer application did not significantly improve growth over the single application, probably due to clipping being done soon after the second application.

Fertilizers generally increased flowering tiller density on the raw spoils but only the split application of 80-40-80 resulted in significant improvement. On the top-dressed spoils, flowering was much greater, and all but the 40-20-40 fertilizer significantly improved flowering over the control. An interesting seeding rate/fertilizer interaction on the top-dressed spoils also became apparent; as seeding rate increased in the plots receiving at least the 60-30-60 rate, the number of flowering tillers decreased.

From these results, Russell and Takyi concluded that fertilizers are necessary for establishing agronomic species, especially on raw spoils. An application of 60-30-60 appears adequate to provide at least 50% cover on raw spoils.

In the native grass trials, fertilizers made small but significant improvements in plant cover over controls in the first season (Table 36.20). There were no significant differences in cover produced by the two fertilizer rates. Cover was very low (0.3 to 1.9%) in all plots.

Table 36.19. Effects of fertilizer rates on dry matter (g/m^2) and number of flowering tillers produced by an agronomic seed mix, Cadomin, Alberta.

	Fertilizer, N-P-K kg/ha				
	0-0-0	40-20-40	60-30-60	80-40-80	80-40-80[a]
Production (g/m^2)[b,c]					
Raw Spoil	0.0[d] a	3.4 ab	7.2 b	8.3 b	8.8 b
Topdressed Spoils	1.4 a	6.8 ab	11.6 ab	15.6 b	16.2 b
Tillers/m^2[b]					
Raw Spoil	0.5 a	1.8 a	2.7 a	11.1 a	27.0 b
Topdressed Spoil	13.6 a	96.4 ab	187.5 bc	197.8 bc	305.6 c

Source: Adapted from Takyi and Russell (1980).

[a] Split application. See Table 36.18 for second season rates.

[b] Values are means of three reps and four seeding rates.

[c] Means followed by a common letter are not significantly different at the 5 percent level (Duncan's Multiple-Range Test).

[d] Production was too poor to allow clipping. In the statistical analysis these were treated as zero.

Table 36.20. Effects of varying fertilizer rates on percent plant cover produced by native grass seed mixture established on raw overburden and top-dressed spoil, Cadomin, Alberta.

	Fertilizer Rate (kg/ha) N-P-K		
	0-0-0[a]	40-20-40	80-40-80
First Season Cover (%)[b,c]			
Raw Spoil	0.5 b	0.9 a	1.1 a
Top-dressed Spoil	0.9 b	1.5 a	1.7 a
Second Season Cover (%)			
Raw Spoil	0.2 a	6.1 c	3.5 b
Top-dressed Spoil	3.0 a	17.7 b	11.3 ab

Source: Adapted from Takyi and Russell (1980) and Russell and Takyi (1979).

[a] Fertilizer rates reduced in second season to 40-20-13 and 80-40-25.

[b] Mean value based on three reps, two seeding rates, and four nurse crops.

[c] Means followed by a common letter are not significantly different at the 5 percent level (Duncan's Multiple - Range Test).

In the second season, cover was much higher, especially on the top-dressed plots. Fertilizers significantly improved cover on raw spoil and top-dressed plots, with the lowest fertilizer level providing the greatest cover. In the top-dressed plots only the lower fertilizer level significantly improved plant cover. Russell and Takyi noted that these results suggest that the native grasses in the seed mix would not respond well to a high fertility regime.

Regier (1973) studied the effects of various levels of NPK on yields of inoculated Medicago sativa cv. Vernal grown in pots containing coal refuse from Blairmore, Alberta.

Nitrogen was supplied as NH_4NO_3, phosphorus as $CaHPO_4$, and potassium as KCl. Nutrients were applied at the time of seeding. Seedlings were thinned to 10 per pot and plants watered frequently.

Data on the first harvest and total yield from four harvests are presented in Table 36.21. Aboveground dry matter yield at the first harvest was significantly greater for those pots receiving 135 kg/ha N, 14.8 kg/ha P, and any rate of K. For the total yield, the addition of N or K alone did not significantly increase yield over the control; however, the addition of 14.8 kg/ha P alone did increase yield. With the exception of the pot receiving 0, 14.8, and 28 kg/ha NPK, all pots fertilized with P at 14.8 kg/ha had significantly improved yields. Yields were depressed under three of the treatments. Root yields were increased in all pots receiving at least 7.4 kg/ha P and 14 kg/ha K.

From these data Regier (1973) concluded that Medicago in these spoils responded most strongly to the addition of phosphorus. Nitrogen was beneficial when applied with phosphorus. The addition of potassium did not produce significant yield differences.

Harrison (1979, 1980) summarized the findings of a three-year study of three seed mixes broadcast seeded along the Trans Mountain Pipeline near Windy Point, Alberta. The study investigated the effects of fertilization, three soil amendments, and four establishment methods on emergence, height, vigour, and total cover. The mixtures were seeded in June 1977. In September 1977, six species were seeded in single species trials.

Table 36.21. Mean yield of Vernal alfalfa grown in pots on coal spoils from Blairmore under various fertilizer regimes.

Treatment kg/ha			Ave. Yield, gm [a]		
			Aerial		Roots
N	P	K	First harvest	Total four harvests	
0	0.0	0	1.9	18.1	10
0	0.0	14	1.8	17.5	11
0	0.0	28	1.0	15.4	9
0	7.4	0	2.1	19.7	15
0	7.4	14	2.9	16.3	25
0	7.4	28	3.0	21.3	27
0	14.8	0	2.3	21.8	22
0	14.8	14	2.3	22.1	17
0	14.8	28	3.1	20.9	23
135	0.0	0	2.2	15.2	10
135	0.0	14	1.5	13.3	9
135	0.0	28	1.4	13.6	11
135	7.4	0	1.9	13.5	8
135	7.4	14	2.7	19.2	17
135	7.4	28	3.1	20.0	18
135	14.8	0	4.5	21.9	21
135	14.8	14	4.1	26.8	23
135	14.8	28	4.6	23.4	22

Source: Adapted from Regier (1973).

[a] Least significant difference at the 95% probability level: (a) aerial 1st = 1.6, (b) aerial total = 3.5, (c) roots = 6.

The author has noted several problems with the study, and as much of the data are subjective, the conclusions drawn are very general. Overall cover of the spring seeded mixes, measured in September 1978, was improved by fertilization (Table 36.22), especially on the sand amended plots. By September 1979, cover was only slightly improved by fertilization (Table 36.22).

Fertilization also improved cover of the fall seeded species (Table 36.23). The response to fertilization was greater in 1978 than 1979. The peat amended plots showed the greatest increase in cover with the addition of fertilizers.

Harrison (1979, 1980) concluded that fertilization is important for initial plant development at the site. As time from the application increased, the effect of fertilization diminished. Fertilization appeared to positively affect the emergence of Poa pratensis only.

Ziemkiewicz (1979) studied the effects of removal of fertilization from reclaimed coal spoils in a montane forest (elevation = 1600 m) and a subalpine zone (elevation = 2100 m) near Sparwood, British Columbia. In August 1976, a series of paired plots was set out on each reclaimed area. In June 1977, one of the pair was fertilized with 13.0 g/m^2 N, 6.9 g/m^2 P and 8.3 g/m^2 K as Cominco 13-16-10. The other was left unfertilized. Plots had been fertilized for the three preceeding years. Dry-weights of shoots, roots, and detritus were assessed over a 14-month period.

In the subalpine area, the fertilized plots showed a large increase in shoot biomass and nearly twice as much root biomass (Figure 36.3). The amount of detritus decreased slightly in the fertilized plots. The author noted that a more important factor may be the accumulation of large amounts of N and P in the undecomposed detritus of the unfertilized plots. This accumulation of nutrients coupled with slow detrital decomposition in subalpine areas may lead to difficulties in maintaining a self-sustaining plant community without added fertilizers.

Table 36.22. Effects of fertilization on percent cover of three seed mixes sown near Windy Point, Alberta.

Amendment	1978 Assessment		1979 Assessment	
	Fertilizer[a]	No Fertilizer	Fertilizer	No Fertilizer
Control	37.8[b]	32.4	78.1	73.3
Peat	34.8	27.6	64.5	65.0
Sand	34.8	19.2	56.2	46.3
Overall Mean	35.7	26.4	66.3	61.6

Source: Adapted from Harrison (1980).
[a] 16-20-0 fertilizer added at 0.04 kg/m².
[b] Values are means of three seed mixes

Table 36.23. Effects of fertilization on percent cover of fall seeded species sown near Windy Point, Alberta.

Treatment	1978 Assessment		1979 Assessment	
	Fertilizer	No Fertilizer	Fertilizer	No Fertilizer
Control	29.8[a]	19.6	43.1	43.0
Peat	35.7	23.1	46.5	47.4
Sand	30.0	24.9	40.2	38.1
Mean	31.8	22.5	43.3	42.8

Source: Adapted from Harrison (1980).
[a] Values are means of six single species trials.

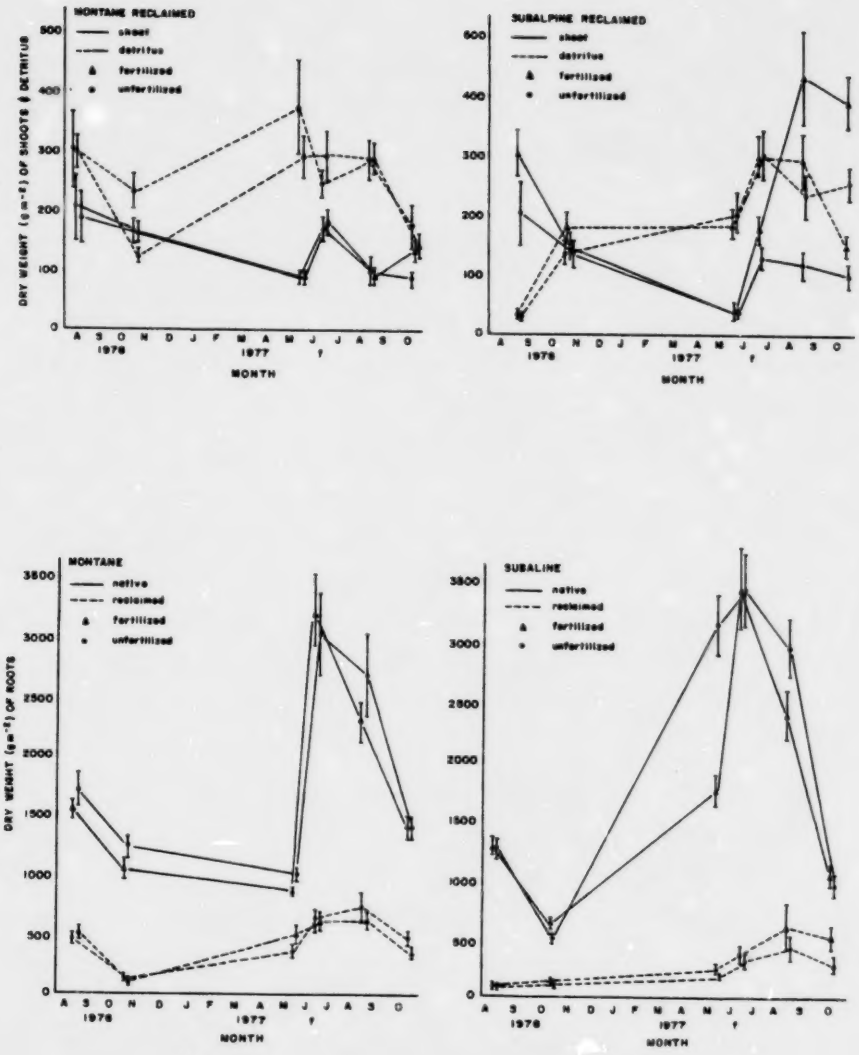


Figure 36.3. The distribution of organic matter in roots, shoots and detritus in a reclaimed British Columbia coal mine spoil. The letter "f" indicates the date of fertilization. Each data point is the mean of 15 observations and is bracketed by the standard deviation of the mean.

Source: Ziemkiewicz (1979:200-201)

In the montane region, water stress due to drought conditions killed much of the standing crop. The fertilized plots produced more detritus, the same shoot and less root biomass by the end of the sampling period. Ziemkiewicz felt that fertilization stimulated shoot production at a time when soil moisture began to limit shoot biomass, thus any additional shoot production died. He noted that the results would have been different in a wetter year.

From these studies, Ziemkiewicz concluded that maintenance fertilization is necessary in the subalpine area but that the low elevation area, with demonstrated nutrient cycling capabilities, need not receive additional fertilization.

Gardiner and Stathers (1979) examined the effects of phosphorus additions on growth of Medicago sativa cv. Rambler seeded with Festuca rubra cv. Boreal on spoils at the Fording Coal operations, British Columbia (elevation = 1700 m). Two types of spoils were studied: (1) waste rock (sandstone and shale), and (2) overburden (calcareous glacial till).

Phosphorus was applied at rates ranging from 0 to 1600 kg/ha of P_2O_5 and treble superphosphate. Nitrogen and potassium were added at 50 kg/ha. The fertilizer was broadcast prior to seeding and incorporated to a depth of 15 cm using a rototiller. The two species were broadcast seeded as a mixture at 30 kg/ha. The legume comprised two thirds of the mixture.

In the first growing season, plant density was not significantly affected by phosphorus addition but plant height was significantly increased by the same addition (Figure 36.4). Maximum growth was attained at 400 kg/ha P on waste rock while height was still increasing at 1600 kg/ha P on the overburden p'ots.

In the second season, both percent occurrence of legumes in the stand (Figure 36.5) and plant biomass (Figure 36.6) increased with increasing P. Approximately four times as much phosphorus was required to obtain 50% legume content on overburden as on waste rock (Figure 36.5). There was no substantial increase in biomass produced when P was doubled from 800 to 1600 kg/ha.

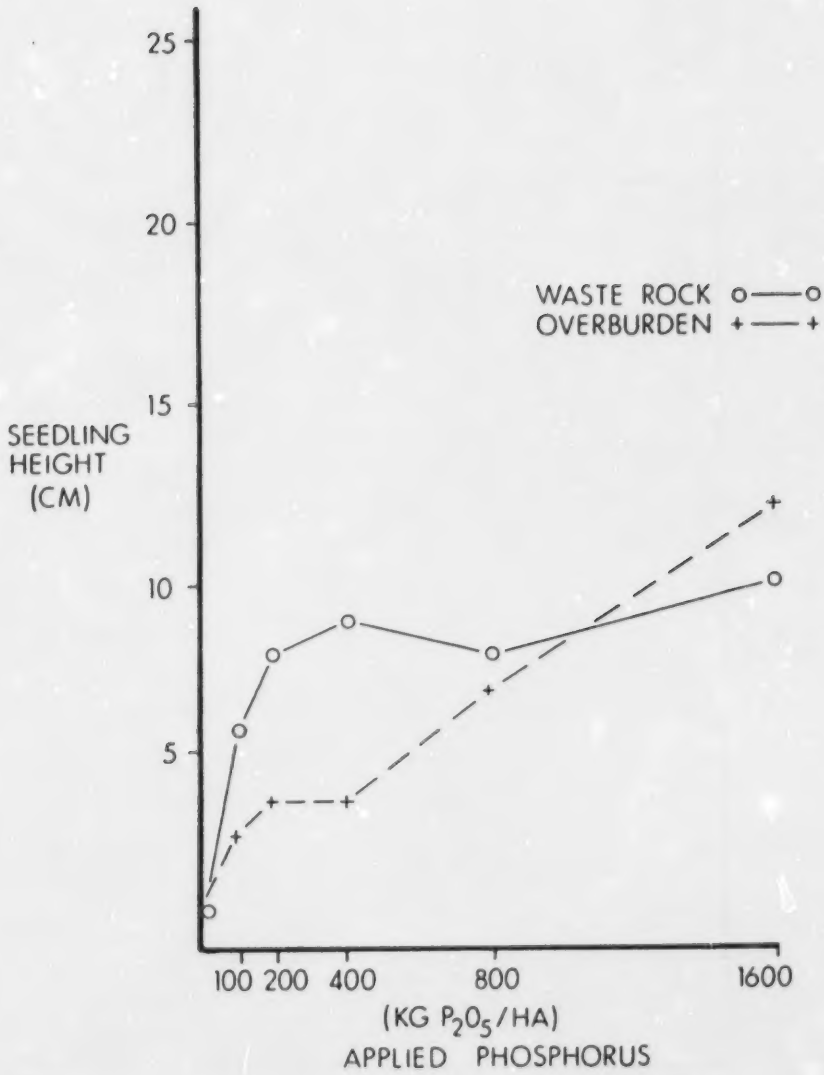


Figure 36.4. Effect of phosphorus on legume seedling growth. Rambler alfalfa sown on two coal spoil materials at Fording Coal, British Columbia.

Source: Gardiner and Stathers (1979:230)

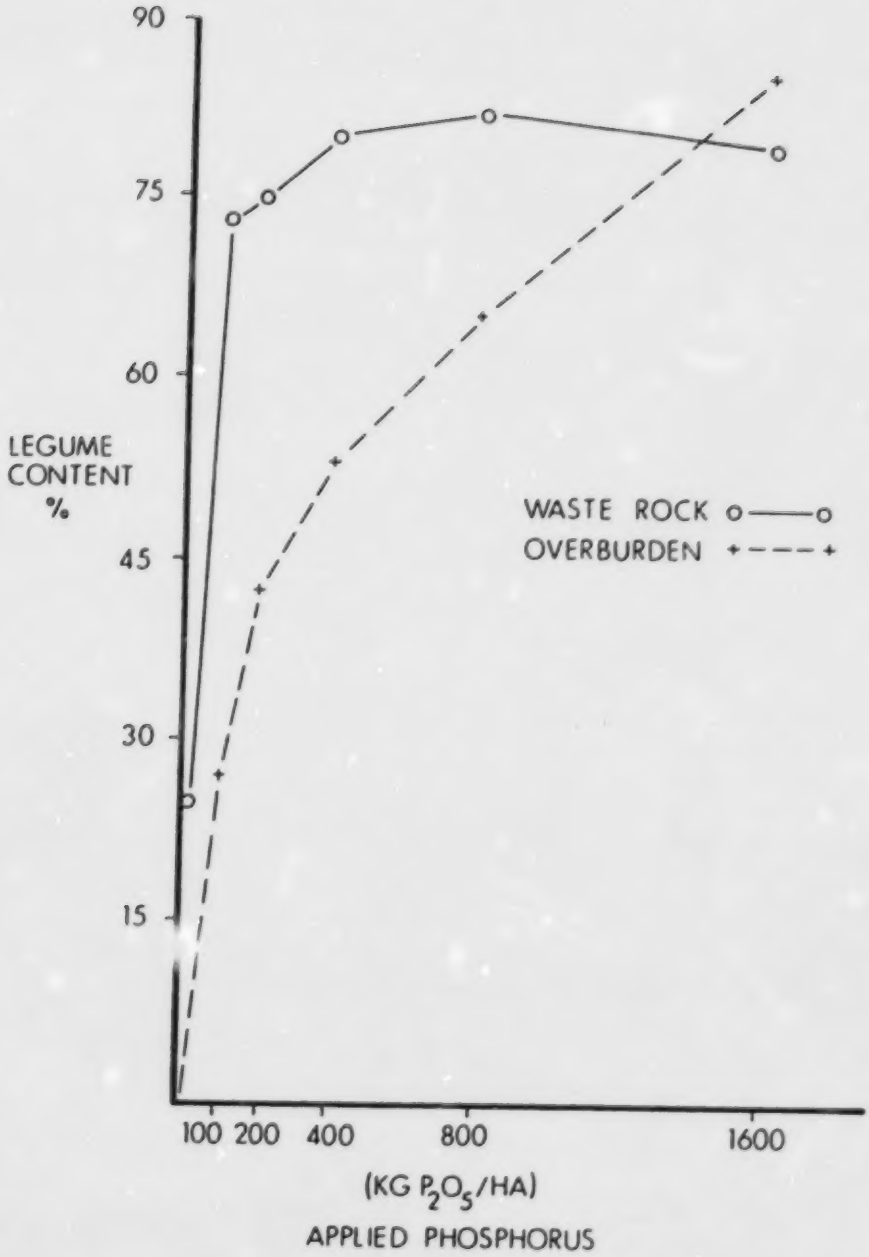


Figure 36.5. Effect of phosphorus on legume content. Rambler alfalfa seeded with Boreal creeping red fescue on two coal spoil materials at Fording Coal, British Columbia.

Source: Gardiner and Stathers (1979:233)

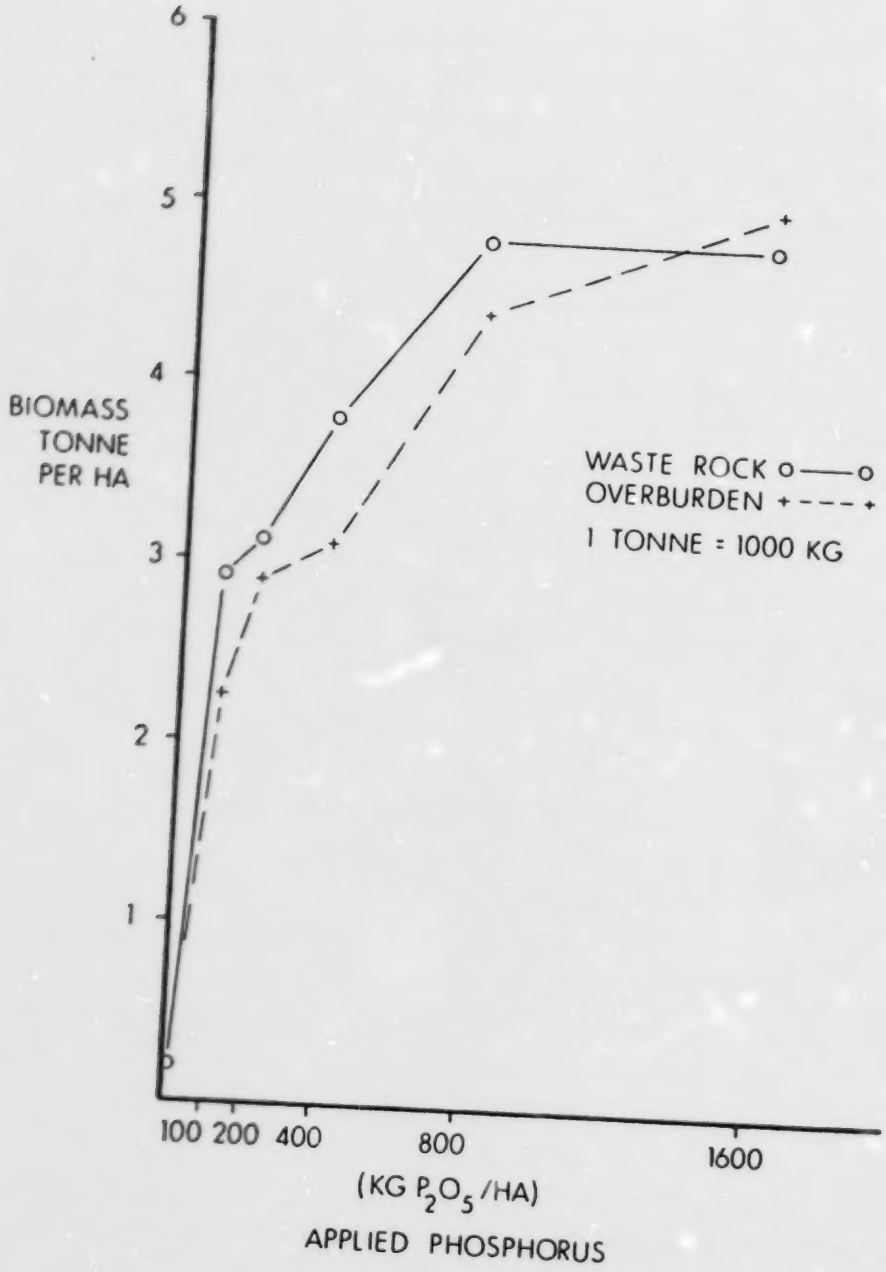


Figure 36.6. Effect of phosphorus on organic matter production of an alfalfa/brome mix sown on two coal spoil materials at Fording Coal, British Columbia.

Source: Gardiner and Stathers (1979:234)

From these early results Gardiner and Stathers (1979) concluded that phosphorus was limiting to legume growth on waste materials at this mine, and that large quantities were required to achieve high levels of organic matter and nitrogen production. They felt that an application of 800 kg/ha was necessary on waste rock and 1600 kg/ha on overburden.

Fyles (1979) studied the effects of four levels of both nitrogen and phosphorus on the growth of grasses previously sown on coal spoils at two sites near Sparwood, British Columbia. The four levels of N tested were 0, 28, 56, and 112 kg/ha, while P was tested at 0, 56, 112, and 224 kg/ha P_2O_5. Nitrogen was applied as urea (46-0-0) and phosphorus as treble superphosphate (0-45-0). The sites had received maintenance fertilizers for several years. The Harmer study site (elevation = 2000 m) was dominated by Dactylis glomerata, Phleum pratense, and Festuca rubra. The Erickson study area (elevation = 1500 m) was dominated by Agropyron intermedium, A. cristatum and Poa compressa. Treatments were evaluated in late August according to dry matter production of aerial biomass.

From these early results Fyles concluded that:

1. Where water is the limiting factor, as at the Erickson site, increased fertilization may not provide an increase in vegetative production, and is therefore not a viable investment of reclamation dollars.
2. Gross variation in soil characteristics and associated plant production within very short distances, as at the Harmer site, make it difficult to provide an overall best fertilizer for reclamation.

The British Columbia Ministry of Energy, Mines and Petroleum Resources (1978) reported on the success of reclamation trials at coal mines and well sites in the northern coal block region of British Columbia. Denison Coal Limited set up plots on eight previously disturbed sites to assess the effects of fertilization on agricultural grasses and legumes. Six plots were located at high elevation (1700 m)

trench sites which had been back-filled and contoured and two at lower elevation (1100 m) abandoned gas well sites.

Fifteen species were tested in single species and mixed trials (Tables 36.24 and 36.25). Plots were seeded between 30 June and 04 July 1976. Seeding rates for single species trials were 45 kg/ha for all grasses and Onobrychis, and 28 kg/ha for all legumes. Seed mixes were spread at the rate of 45 kg/ha. Legume seeds were inoculated just prior to seeding. Plots were raked, seeded, fertilized, and then re-raked to cover seed and fertilizer.

The three fertilizer rates used were: (1) a control (no fertilizer); (2) optimum rate (36 kg N, 45 kg P_2O_5, 22 kg K_2O per hectare); and (3) double rate (72 kg N, 90 kg P_2O_5, 45 kg K_2O per hectare).

The plots were assessed for percent cover on 20 August 1976 (two months after seeding) and August 1977. These data are summarized in Figures 36.7 to 36.9 as average cover values for the eight sites. The reader is encouraged to read the report to obtain site descriptions and the raw data for each site. Cover values varied considerably between sites.

In general, cover in both years increased with increasing fertilizer levels for most species and mixes. Legumes did poorly at high elevation sites and did not show much improvement with fertilization (Figure 36.8). Below the tree-line, however, legumes showed definite improvement with fertilization.

The B.C. Ministry of Energy, Mines and Petroleum Resources noted that these data have not been statistically analysed and thus it is not possible to determine if growth is significantly improved by the addition of the double fertilizer rate as compared to the optimum rate. Certain species do seem to benefit from the extra fertilizer, especially in plots below the tree-line including Festuca rubra, Poa compressa, Agrostis alba, Trifolium pratense and T. repens.

Plots were also set out in July 1977 at two well sites on Bullmoose Mountain (elevation = 1125 and 1780 m). Twenty-seven species

Table 36.24. Agricultural species tested in field trials, Quintette, British Columbia, 1976.

Single Species Trials			
Grasses		Legumes	
Common Name	Latin Name	Common Name	Latin Name
Creeping red fescue	Festuca rubra	Sweet clover	Melilotus sp.
Brome grass	Bromus inermis	Birdsfoot trefoil	Lotus corniculatus
Meadow foxtail	Alopecurus pratensis	Alsike clover	Trifolium hybridum
Meadow fescue	Festuca elatior	Red clover	Trifolium pratense
Timothy	Phleum pratense	Alfalfa	Medicago sativa
Slender wheatgrass	Agropyron trachycaulum	Sainfoin	Onobrychis viciaefolia
Canada bluegrass	Poa compressa	White clover	Trifolium repens
Red top	Agrostis alba		

Source: Adapted from British Columbia Ministry of Energy, Mines and Petroleum Resources (1978:62)

Table 36.25. Agricultural species tested in field trials, Quintette, British Columbia, 1976.

Seed Mix A		Seed Mix B		Seed Mix C	
Species	% in seed mix	Species	% in seed mix	Species	% in seed mix
Creeping red fescue	15	Creeping red fescue	10	Creeping red fescue	5
Timothy	15	Timothy	20	Brome grass	10
Brome grass	15	Brome grass	20	Red top	10
Meadow foxtail	10	Canada bluegrass	15	Meadow fescue	10
Slender wheatgrass	10	Alsike clover	10	Slender wheatgrass	15
Red clover	15	Birdsfoot trefoil	10	Canada bluegrass	10
Sainfoin	10	Alfalfa	15	Sainfoin	15
Sweet clover	10			White clover	15
				Birdsfoot trefoil	10

Source: Adapted from British Columbia Ministry of Energy, Mines and Petroleum Resources (1978:62)

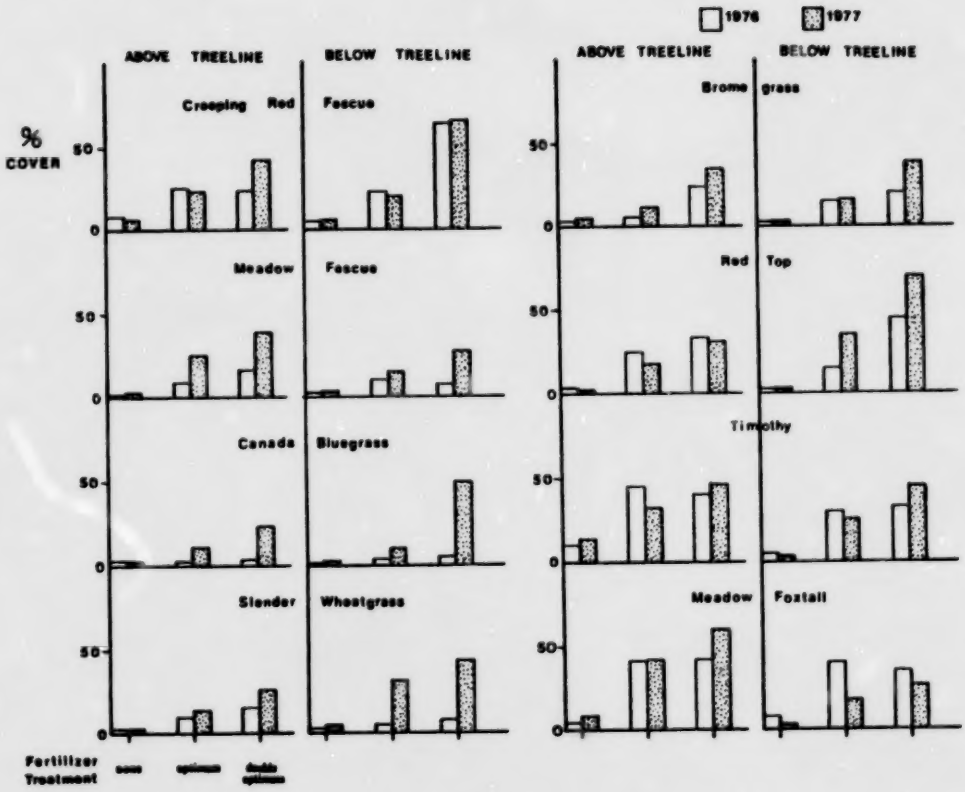


Figure 36.7. Effects of fertilizer rate on average growth (% cover) of single grass species trials above treeline (7 sites) and below treeline (2 sites), near the Denison Coal Mine, British Columbia.

Source: British Columbia Ministry of Energy, Mines and Petroleum Resources (1978:26)

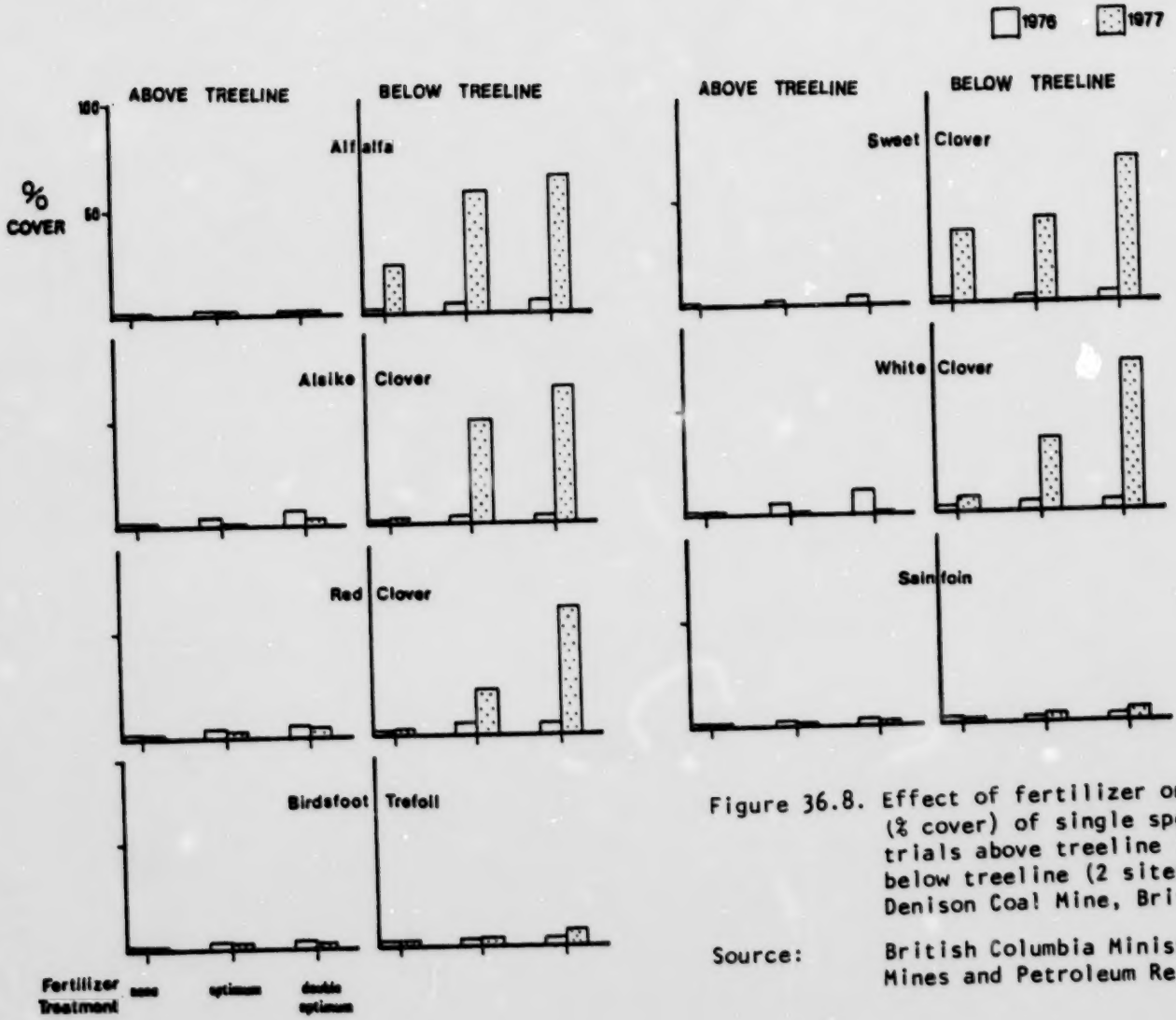


Figure 36.8. Effect of fertilizer on average growth (% cover) of single species legume trials above treeline (7 sites) and below treeline (2 sites), near the Denison Coal Mine, British Columbia.

Source: British Columbia Ministry of Energy, Mines and Petroleum Resources (1978).

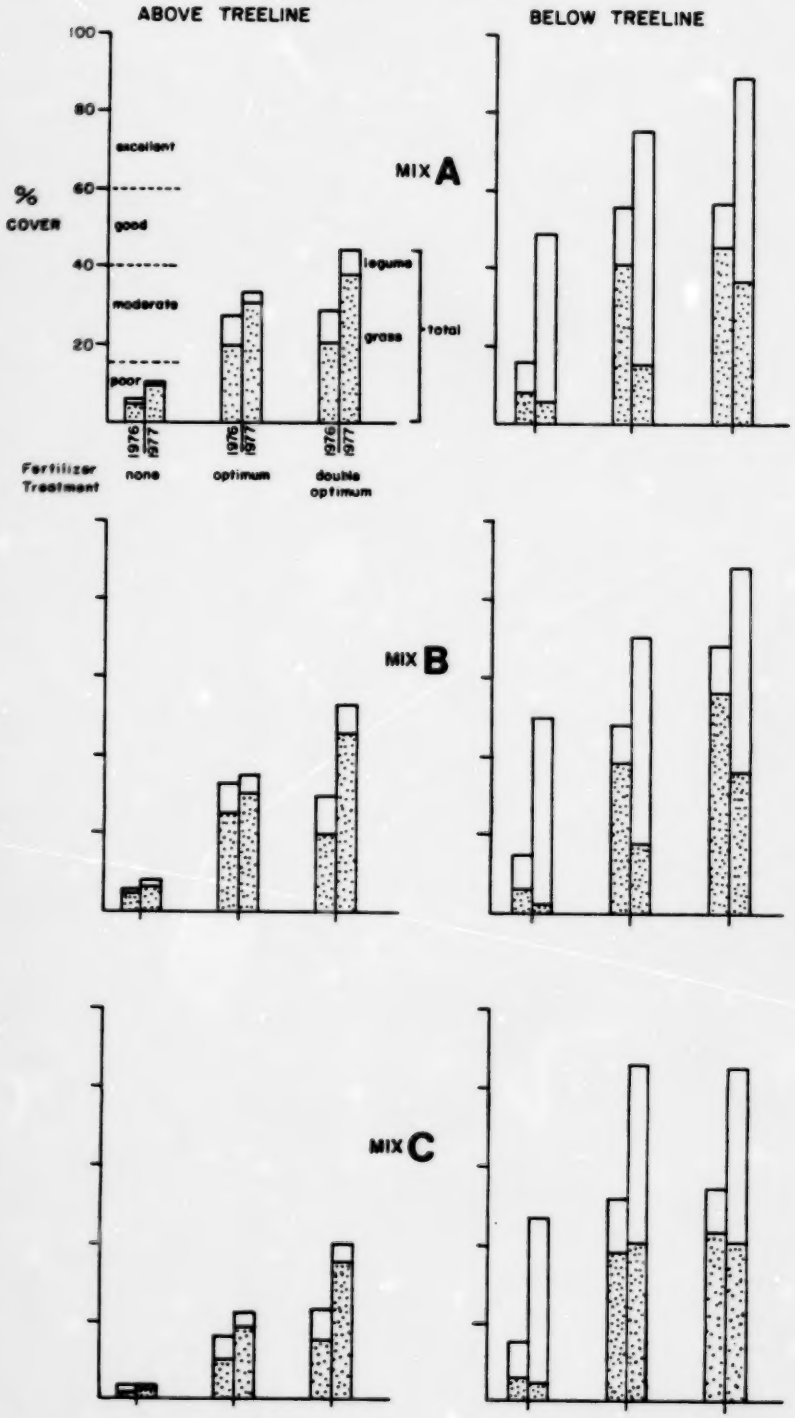


Figure 36.9. Effect of fertilizer rate on average growth (% cover) of species mix trials above treeline (7 sites) and below treeline (2 sites) near the Denison Coal Mine, British Columbia.

Source: British Columbia Ministry of Energy, Mines and Petroleum Resources (1978:30)

and two mixes were tested under four fertilizer regimes: (1) control, 0 kg/ha N, P, and K; (2) half recommended level, 18, 22, and 11 kg/ha N, P, and K; (3) recommended level, 36, 45, and 22 kg/ha N, P, and K; and (4) double recommended level, 72, 90, and 45 kg/ha N, P, and K. Species and seeding rates are shown in Table 36.26.

Plots were assessed for percent cover two months after seeding. Several species showed improvements in cover with increasing fertilizer inputs (Table 36.26), for example, Festuca elatior, Lolium perenne, Dactylis glomerata, Agrostis alba, Alopecurus pratensis, Medicago sativa cv. Ceres, Trifolium pratense, Melilotus sp., and mix A. Several of the other species including Festuca ovina var. duriuscula, Agropyron cristatum, and Medicago sativa cv. Drylander showed improved growth with the addition of fertilizer at half the recommended rate but no marked improvement with additional fertilizer.

Klock, Tiedemann and Lopushinsky (1975) studied the effects of fertilizers on establishment and growth of five grass/legume mixes sown on fire-lines in north-central Washington. Three study sites in the Wenatchee and Okanogan National Forests were chosen in areas severely disturbed by tractor operations:

1. Dinkelman Ridge, elevation 1250 m. Soils are derived from Swauk sandstone parent material and are generally loamy sands.
2. Sugarloaf Corral, elevation 1540 m. Soils are derived from Swauk sandstone.
3. Handy Springs, elevation 2000 m. Soils are predominatly volcanic ash with some pumice.

Varieties and seeding rates for the species in each of the five mixes are shown in Table 36.27. Legumes were not inoculated. Half of the plots were fertilized at a rate of 336 kg/ha of ammonium phosphate sulfate (16-20-0-15). Data on ground cover for each species in the mixes were collected in August of the first and second growing seasons.

In general, fertilization improved cover (Table 36.27), emergence, and establishment of the species. Phleum pratense and Secale

Table 36.26. Growth (% cover) of spring seeded test plots, Peace River coal block, British Columbia, 1977.

Site		77-1				77-2				77-3[a]			
Layout		I				I				I			
Elevation		1125				1780				1870			
Date seeded (day/mo/yr)		5-7-77				7-7-77				9-7-77			
Date assessed (day/mo/yr)		30-8-77				29-8-77				15-9-77			
Fertilizer treatment	Seed Rate (kg/ha)	0	0.5	1	2	0	0.5	1	2	0	0.5	1	2
Creeping red fescue	22	3	10	20	20	3	10	10	20	+	1	3	3
Meadow fescue	56	10	10	30	50	10	10	10	30	+	2	1	1
Hard fescue	22	3	10	10	10	3	10	10	20	+	1	1	2
Kentucky bluegrass	11	3	10	20	10	3	10	10	10	0	1	1	1
Canada bluegrass	11	3	20	20	10	3	10	10	10	0	1	2	2
Perennial ryegrass	56	3	20	40	60	10	30	30	60	1	3	5	4
Tracenta hentgrass	11	3	10	0	3	3	10	20	30	1	2	2	10
Crested wheatgrass	56	10	20	20	20	10	20	20	30	3	3	2	5
Pubescent wheatgrass	56	3	10	20	30	10	10	10	20	1	1	1	1
Slender wheatgrass	56	10	10	20	10	10	10	20	30	1	1	2	6
Streambank wheatgrass	56	10	20	20	30	10	20	30	30	1	1	2	3
Bromegrass	56	10	30	40	30	10	10	20	30	+	1	2	1
Orchardgrass	22	10	20	20	40	10	20	40	40	1	2	3	4
Redtop	11	0	3	10	10	10	10	30	40	0	1	2	6

continued...

Table 36.26. Continued.

Site		77-1				77-2				77-3[a]			
Layout		I				I				I			
Elevation		1125				1780				1870			
Date seeded (day/mo/yr)		5-7-77				7-7-77				9-7-77			
Date assessed (day/mo/yr)		30-8-77				29-8-77				15-9-77			
Fertilizer treatment	Seed Rate (kg/ha)	0	0.5	1	2	0	0.5	1	2	0	0.5	1	2
Reed canarygrass	22	3	10	10	20	0	3	20	10	1	2	2	4
Russian wild ryegrass	56	10	10	20	30	10	10	10	10	1	3	2	2
Timothy	11	10	10	10	20	10	10	20	30	1	2	3	5
Meadow foxtail	39	3	10	20	40	10	20	20	50	+	2	6	10
Alfalfa - ceres	28	20	40	40	40	20	20	20	40	+	+	0	1
Alfalfa - drylander	28	10	10	10	10	10	20	20	20	0	0	0	0
Alsike clover	28	10	10	10	20	10	20	20	30	0	0	0	+
Red clover	28	10	20	20	30	10	20	40	40	+	1	1	2
Birdsfoot trefoil	28	10	10	10	10	10	10	10	10	1	1	1	+
Sweet clover	28	20	30	40	60	20	20	20	30	0	0	0	0
White clover	28	10	10	10	30	10	30	40	40	1	1	1	1
Cicer milkvetch	28	3	3	3	3	3	3	3	10	0	0	0	0
Sainfoin	39	10	10	20	20	10	10	10	10	0	0	0	0
Mix A	56	10	20	30	30	10	20	30	50	2	4	8	8
Mix B	56	10	10	20	10	10	20	20	30	0	3	7	7

continued...

Table 36.26. Concluded.

Source: British Columbia Ministry of Energy, Mines and Petroleum Resources (1978:92)

a This site was inadvertently over-seeded with the forestry mix, therefore, it was difficult to distinguish species.

Mix A: Boreal crf = 40%
Climax timothy = 20%
Alsike clover = 40%

Mix B: Boreal crf = 20%
Redtop = 20%
Meadow foxtail = 20%
Bromegrass = 10%
Timothy = 10%
Alsike clover = 20%

Table 36.27. Fertilized and unfertilized foliar cover on experimental plots in north central Washington, for mixed plant species two years after planting.

Common name	Scientific name	Variety	Seeding rate (kg/ha)	Dinkelman Ridge		Sugarloaf Corral		Hendy Springs	
				Fert. %	No Fert. %	Fert. %	No Fert. %	Fert. %	No Fert. %
Mix 1:									
Smooth brome	Bromus inermis	Manchar	11.2	10	0	5	0	0	8
Timothy	Phleum pratense	Drummond	1.1	28	13	42	0	45	30
Hard fescue	Festuca ovina var. duriuscula	Durar	2.6	10	3	0	0	0	0
Crested wheat grass	Agropyron desertorum	Nordan	7.3	8	0	0	0	0	2
	Total cover (above species)			56	16	47	0	45	40
Mix 2:									
Annual wheat	Agropyron triticeum		27.2	0	0	0	0	0	0
Common sainfoin	Onobrychis viciaefolia	Onar	19.7	0	0	0	0	0	0
Cereal rye	Secale cereale		4.4	0	0	0	0	0	0
Common ryegrass	Lolium sp.		4.7	0	0	5	0	0	0
Mustard	Brassica sp.	Giant	5.4	0	0	0	0	0	0
	Total cover (above species)			0	0	5	0	0	0

continued...

Table 36.27. Continued.

Common name	Scientific name	Variety	Seeding rate (kg/ha)	Dinkelman Ridge		Sugarloaf Corral		Hendy Springs	
				Fert. %	No Fert. %	Fert. %	No Fert. %	Fert. %	No Fert. %
Mix 3:									
Annual wheat	Agropyron triticeum		23.0	0	0	0	0	0	0
Common sainfoin	Onobrychis viciaefolia	Onar	14.4	0	0	0	0	0	0
Cereal rye	Secale cereale		16.5	0	0	0	0	0	0
Smooth brome	Bromus inermis	Manchar	7.0	3	7	0	0	2	0
Timothy	Phleum pratense	Drummond	0.7	0	3	40	0	42	10
Hard fescue	Festuca ovina var. duriuscula	Durar	1.5	0	3	2	0	0	0
Crested wheatgrass	Agropyron desertorum	Nordan	4.4	3	0	0	0	0	0
	Total cover (above species)			6	13	42	0	44	10

continued...

Table 36.27. Concluded.

Common name	Scientific name	Variety	Seeding rate (kg/ha)	Dinkelman Ridge		Sugarloaf Corral		Hendy Springs	
				Fert. %	No Fert. %	Fert. %	No Fert. %	Fert. %	No Fert. %
Mix 4:									
Mustard	Brassica sp.	Florida broadleaf	12.0	0	0	0	0	0	0
Mustard	Brassica sp.	Giant Curl	12.0	0	0	0	0	0	0
	Total cover (above species)			0	0	0	0	0	0
Mix 5:									
Garden pea	Pisum sativum	Austrian	223.0	0	0	7	0	0	0
Rape	Brassica sp.		32.3	0	0	0	0	0	0
	Total cover (above species)			0	0	7	0	0	0

Source: Klock, Tiedemann and Lopushinsky (1975:5).

cereale showed the greatest improvement in cover. Klock, Tiedemann and Lopushinsky noted that species seeded in mixtures did not perform as well as those seeded in single species trials. The authors felt that a starter fertilizer treatment is imperative for reclaiming high altitude regions.

Brown and Johnston (1976) studied the effects of fertilizers on the establishment and growth of native or introduced species sown on copper/silver/gold mine tailings at McLaren Mine, Beartooth Mountain, Montana (elevation = 2950 m). Seventy-two plots were set up on rough-graded mine spoil. Topsoil was spread to a depth of 20 cm on one half of the plots. Half of each of these plots were fertilized with a granular 16-16-16 mixture applied at a rate equivalent to 111 kg N/ha. Plots were broadcast seeded in the fall to mixtures of native or introduced species (Table 30.1) at a rate of 56 kg/ha. Fertilizer was applied after the seed and plots were thoroughly raked and packed. Plant density data were recorded in September of the following year.

Introduced species on the topsoiled plot showed no appreciable effects of fertilizer treatment. Native species responded to fertilization on both soils (Table 30.2). Plants growing on fertilized plots were taller and had deeper root penetration than the same species on unfertilized plots. Deeper root penetration apparently increases seedling survival during periods of midsummer drought.

The authors concluded that fertilizers improved growth and survival of first-year seedlings and should be incorporated in all reclamation efforts in alpine environments.

Brown et al. (1976) noted that a single application of granular 15-40-5 at a rate equivalent to 111 kg/ha N, raked into the spoil, maintained a level of productivity about 100 times greater over a three-year period than that on unfertilized plots at Iron Mountain, Montana.

Farmer, Richardson and Brown (1976) studied the effects of fertilization, topsoiling, irrigation, and mulching on plant production at a copper/cobalt mine near Salmon, Idaho (elevation = 2012 to 2499 m). Study methods were the same as these used by Farmer et al. (1974) at

the Decker Coal Mine, Montana. Three main plots were set up: (1) topsoiled (20 cm of soil), (2) irrigated, and (3) a control (raw spoil). Superimposed upon these main treatments were fertilizer and mulch treatments. Seed mixtures of native, introduced, and native plus introduced species (Table 33.17) were sown on each treatment at 28.6 kg/ha.

To support plant growth, all the overburden materials needed lime. Two months before planting, the overburden materials were ripped to a depth of 25.4 cm and limed at the rate of 1749 kg/ha CaO. The top-dressing soil required a greater liming rate than overburden materials because of greater cation exchange capacity. After the lime was spread over the surface, the site was harrowed several times to a depth of about 15 cm. No additional lime was applied.

In October, the soil materials were harrowed several times. Larger rocks, brought to the surface by harrowing, were removed with a rock rake. During planting special measures were taken to ensure that treatments were applied uniformly, and that each was confined to the appropriate subplot area. The fertilizer and seed were separately packaged with silica sand, a carrying agent, and applied by a small seed spreader. Rice hulls were used with the seed. Granular 18-46-0 fertilizer was spread at 487.6 kg/ha and raked in. Seed was then applied, lightly raked, and all plots were packed with a Brillion Culti-Packer. Plots were fertilized one year after seeding as well.

Data on stand density and dry-weight production were taken in October of the first growing season and September of the second. Farmer, Richardson and Brown (1976) restricted their discussions on production to second season growth.

Fertilizer increased seedling emergence on the mulched control plots (95.1 versus 68.9 seedlings/m^2) but had no effect on the unmulched and topsoiled plots. Visual estimates indicated emergence on irrigated plots was similar to that observed on the control plots.

Fertilizer increased plant production on all plots but was most effective in combination with topsoiling and mulching (Figure 30.1).

The authors noted that fertilization appeared to be a requirement, along with topsoiling, for successful revegetation at this mine.

Berg and Barrau (1978) studied the effects of adding nitrogen to disturbed sites in subalpine areas of Colorado. The first study site was an exposed, 20% slope of glacial till at an elevation of 3350 m near Climax, Colorado. The soils, a combination of sandy loam and gravel, had a pH of 8.1, and were extremely low in extractable phosphorus and moderately low in exchangeable potassium.

Before seeding, triple superphosphate was broadcast over the area at the rate of 168 kg/ha P_2O_5. After furrowing, the plots were broadcast seeded to a mixture of Bromus inermis, Phleum pratense, Agrostis alba, Festuca ovina var. duriuscula, Dactylis glomerata, and Trifolium repens. The nitrogen (N) treatments broadcast in June as NH_4NO_3 are shown in Table 36.28.

Good grass stands were established though there were only scattered T. repens plants. Ground cover data collected in August of the fourth growing season indicated that the residual effect of N added in the first season was small, while cover was much better in stands fertilized in all years (Table 36.28).

Berg and Barrau noted that the increases in cover per unit of fertilizer, in plots fertilized for three or four years, were not as large as those obtained in plots fertilized for two years. They suggested that sites such as these be fertilized for two years to produce reasonable vegetation stands then not refertilized until stands exhibit N-deficiency symptoms.

The second study site was located on a cut-slope adjacent to a highway. The subsurface glacial till was approximately 70% rock and gravel. The sandy loam surface material had a pH of 6.5, was low in extractable phosphorus, and moderately low in exchangeable potassium. The N treatments were applied to existing grass stands established two to three years previously when the highway was constructed. The stands, dominated by Bromus inermis and Phleum pratense, exhibited an N deficiency when the first N treatments were applied in June 1974. The N treatments, broadcast in June as NH_4NO_3, are shown in Table 36.29.

Table 36.28. Effects of nitrogen fertilization on percent cover of a sub-alpine grass stand, Colorado.

Treatment & Year Applied	Total N Applied kg/ha	% Ground Cover
No N	0	5
67 kg N 1974	67	10
67 kg N 1974 & 1975	134	25
67 kg N 1974, 1975 & 1976	201	33
67 kg N 1974, 1975, 1976 & 1977	268	40

Source: Adapted from Berg and Barrau (1978).

Table 36.29. Effects of nitrogen fertilization on percent ground cover of a sub-alpine grass stand, Colorado.

Treatment & Year Applied	Total N Applied kg/ha	% Ground Cover
No N	0	10
56 kg N 1974	56	35
56 kg N 1974 & 1975	112	40
56 kg N 1974, 1975 & 1976	168	35
56 kg N 1974, 1975, 1976 & 1977	224	40

Source: Adapted from Berg and Barrau (1978).

Data on percent ground cover, collected in the fourth growing season, indicated that fertilizers improved ground cover over the control (Table 36.29), but that there were no responses to N applied after the first season.

Berg and Barrau (1978) assumed that the area was fertilized initially (1971/72) which meant that the 1974 fertilization was acting as a maintenance input. For this reason they again concluded that on N-deficient coarse soils, nitrogen should be applied in the first year and then again in the second or third growing seasons. Following that, they suggested periodic inputs when N-deficiency symptoms developed (perhaps every three or four years).

In New Zealand, Dunbar (1971) studied the effects of fertilizers on establishment of grasses and forbs on three exposed subalpine sites. All soils were severely eroded, strongly leached, high country yellow-brown earths. Ten species were sown in individual plots in November at a rate calculated to give one viable seed per 6.5 cm^2, with the exception of Secale montanum which was seeded at half this rate.

The fertilizer was broadcast with the seed as a mix of superphosphate (502 kg/ha), calcium ammonium nitrate (502 kg/ha), magnesium sulphate (125.5 kg/ha), potassium sulphate (125.5 kg/ha), copper sulphate (11.2 kg/ha), and sodium molybdate (0.35 kg/ha).

Two months after seeding, observations showed that fertilization had improved the vigour of the plants markedly. However, there were no significant effects of fertilizer treatment on plant densities within each site. Response to the fertilizer was species and site specific, making even generalized conclusions difficult. Plants on fertilized plots were observed to continue growth through summer and autumn while unfertilized plants appeared to grow little after January. The few seedlings which survived winter were restricted to the fertilized plots.

In a second study, Dunbar (1974) set out field trials at 10 sites to test the effects of four fertilizer treatments on three species and a mix for establishing vegetation on eroded mountain sites

in South Island, New Zealand. The sites were at elevations ranging from 840 m to 1430 m and all soils had been greatly disturbed or reduced in depth by erosion. Soils were mostly B and C horizons from yellow-brown earths, acid, and very low in phosphorus and exchangeable bases.

The trial design at each site contained four plant species treatments and four "fertilizer" treatments in a 64 plot, single replicate, factorial design. Plant treatments were: (1) Trifolium repens cv. Grasslands Huia, 9.4 kg/ha; (2) Holcus lanatus cv. Massey Basyn Yorkshire 4.7 kg/ha; (3) Dactylis glomerata cv. Grasslands Apanui, 15.1 kg/ha; and (4) a mixture of 1, 2, and 3 at 29.2 kg/ha.

The forms and rates of application of fertilizers and lime are shown in Table 36.30. All plots received phosphorus as a basal treatment, and in addition, the H. lanatus and D. glomerata plots received nitrogen. Sulphur, magnesium, lime, and a mixture of potassium, boron, copper, and molybdenum were the four factorial treatments. Fertilizer, lime, and seed were applied by hand without prior or subsequent disturbance of the ground surface, except for removal of boulders with a diameter larger than 30 cm.

Subjective assessments of species vigour and ground cover were made for first season growth and an assessment of ground cover was made at the end of the third growing season. The response to magnesium was highly significant (Table 36.31), confirming results from earlier greenhouse trials. The improved vigour of plants receiving the potassium plus minor elements treatment was attributed to potassium, primarily because previous greenhouse trials had shown many positive responses to K but none to minor elements. The effects of sulphur and lime were variable.

From these studies Dunbar concluded that fertilizers are required to produce strong seedlings capable of withstanding winter stresses and that maximum growth of a grass/legume mix in these disturbed mountain sites could be attained with a multi-nutrient fertilizer containing N, P, Mg, and K as basic ingredients. Sulphur, which is present in superphosphate, would also be beneficial in most cases.

Table 36.30. Forms and rates of nutrients and lime tested in field trials in New Zealand.

Form	Treatment	Rate kg/ha
Urea	N	108
Monocalcium phosphate	P	56
Calcium sulphate	S	70
Magnesium carbonate	Mg	29
Potassium chloride	K	60
Cupric chloride	Cu	1.41
Sodium tetraborate	B	1.34
Sodium molybdate	Mo	0.11
Ground limestone	$CaCO_3$	1076

Source: Adapted from Dunbar (1974).

Table 36.31. Response to fertilizer and lime treatments at eight eroded sites in New Zealand.

Site	Sulphur			Magnesium			Potassium plus minor elements			Lime		
	a	b	c	a	b	c	a	b	c	a	b	c
Black Birch	+	-	+	+**	+**	+**	+**	+**	+*	+	+	+**
Craigieburn	+**	+**	+	+**	+**	+**	+**	+	+	-	+	+**
Dogs Range	+	+	+	+**	+**	+**	+**	+**	+**	-	-	-
Ohau	-	+	0	+**	+**	+*	+**	+	+*	-	-	-
Dunstan	+**	+	+	+**	+**	+**	+*	+	+	-	+	+
Carrick	+**	+*	+	+**	+**	+**	+**	+	+	-	+	+
Mid Dome	+	+	0	+**	+*	+*	+*	+	0	-	-+	-*
Takitimu	-	-	0	+	+	+	-	-	-*	+	+	0

Source: Dunbar (1974:4)

Note: 1. Responses are for main effects assessed over all plant treatments, (a) by estimates of plant vigour in first season, (b) by estimates of ground cover in first season, (c) by estimates of ground cover in third season after treatment.

2. Level of significance: * Significant at 5% level
** Significant at 1% level

3. + and - indicate positive and negative responses respectively. 0 indicates no response.

McKendrick and Mitchell (1978) examined the response to fertilizer additions of arctic tundra vegetation disturbed by an oil spill. In June 1972, a leak in an old 10.2 cm injection line at Prudhoe Bay, Alaska spilled 750 to 1500 L of Prudhoe Bay crude oil onto a wet tundra site. Cleanup was accomplished by burning a small portion of the site, by use of absorbents on another, and by leaving one portion alone. On 30 June 1972 a series of plots were set out to determine the effects of fertilizers on regrowth of the natural vegetation. A commercial 11-22-22 fertilizer was applied to some plots and others were left unfertilized.

The most noticeable responses were increases in cover, and vigour of sedges and grasses. Dry matter production of vascular plants was almost four times greater on fertilized plots (Table 36.32). There was also an increased tendency to produce inflorescences where fertilizer had been applied. Mosses and liverworts were found growing only in the fertilized plots throughout the four-year study period.

Two years after the spill McKendrick and Mitchell seeded Puccinellia borealis and Secale cereale at 67 and 78 kg/ha, respectively, onto plots which had remained devoid of vegetation. Some plots were fertilized with 160, 190, 110, and 90 kg/ha of N, P, K, and Mg, respectively, while others were not fertilized.

The autumn-seeded P. borealis germinated but the S. cereale failed. The most noticeable effect was the growth of the P. borealis, mosses, and liverworts in the P fertilized plots. Dry matter production of the P. borealis in the fertilized plots improved over the second and third growing seasons to such an extent that production equalled that in natural areas. Although some unfertilized plants survived until the third season, they failed to gain vigour.

Van Cleve (1977) has summarized the results from several studies on the effects of fertilizers on growth of several grasses seeded along the trans-Alaska pipeline between Prudhoe Bay and Fairbanks, Alaska. Methods of site preparation and seeding techniques were not presented in the paper, however, soil chemical and physical properties were presented.

Table 36.32. Response of vascular plant production to fertilizer addition on wet tundra (Prudhoe Bay, Alaska) subjected to an oil spill and subsequently burned.

Growing season	Dry matter production (g/m^2)	
	Fertilized	Unfertilized
1	52	19
2	74	31
3	96	8
4	90	18

Source: Adapted from McKendrick and Mitchell (1978).

In general, Van Cleve (1977:432) noted that "fertilization has a marked favourable impact on the rate, amount, and longevity of cover production. In most cases growth of introduced species without fertilization has shown limited success or no success two to three years after seedling establishment. Extent of depletion of nutrient capital during disturbance coupled with generally low available contents of important nutrients in these cold-dominated soils necessitates the use of fertilizer...."

For the most vigorous species tested (Festuca rubra cv. Arctared), cover production after five years was up to 23-fold greater for fertilized treatments (Table 21.9 and Figure 21.1). With the exception of Festuca and Deschampsia, fertilization had not offset the severe environment at Prudhoe Bay enough so as to result in extended cover production (Table 21.9).

Van Cleve (1977) presented detailed summaries of fertilization effects on selected growth parameters for the best species, after two growing seasons, which emphasize the importance of soil nutrient regime in cold-dominated, disturbed soils. At all study sites where greater than trace amounts of production occurred, fertilization produced marked increases in plant height, numbers of flowers, percentage of cover, biomass, and vegetative reproduction over the controls (Table 36.33). The marked increases in vegetative reproduction (an index of sod formation) with fertilization are important from the standpoint of ground surface stabilization and reflect the ability of certain species to expand protective surface cover on at least a short-term basis.

He noted that field tests with various formulations have shown high phosphorus fertilizers generally produce the best growth response over a wide range of arctic sites; however, more studies are required to provide firm recommendations on formulations and levels of application. The question of the length of time fertilizers are required still remains unanswered. Even the most vigourous of species show declines in cover after four to five years (Figures 21.1 and 21.2). The author stated that most introduced species are undoubtedly beyond the limits of

Table 36.33. Selected growth parameters for best species after 2 seasons of growth, selected at respective revegetation study sites (lower figure is control).

	Arcta red fescue	Boreal creeping red fescue	Durar hard fescue	Nugget poa	Meadow foxtail	Slender wheat grass	Hair grass	Engmo timothy
Prudhoe Bay								
Height (cm)	4.7*(0.3) 2.5 (0.0)	5.1;0		0; 2.0	7.6; 7.6	5.1; 5.1	16.0*(0.8) 6.9 (0.5)	0; 0
Flowers (no/m^2)	4 0	0; 0		0; 0	0; 0	0; 0	0; 0	0; 0
% cover	90.0*(5.0) 16.7 (7.3)	T		T; T	T; T	T; T	88.3 (4.4) 7.3 (6.3)	0; 0
Biomass (g/m^2)	- ; - 0	-; 0		T; T	T ;T	T; T	-; -	0;0
Vegetative repro.	4" 0	0; 0		T; T	T; T	0; 0	4 0	0; 0
Happy Valley								
Height	5.1**(.5) 2.5 (.3)	5;1; 2.5	3.6**(0.5) 2.4 (.4)		5.5 (0.7) 2.8 (0.3)			5.6 (1.1)
Flowers	0; 0	0; 0	0; 0		0; 0			T; 0
% cover	8.3 (3.6) 18.3 (5.0)	T; T	10.0 (3.9) 3.3 (2.3)		13.4 (4.4) 6.7 (3.2)			T; T
Biomass	11.0 (4.5) 3.9 (4.5)	T; T	4.5**(0.1) 0		7.1 (3.2) 0.7 (0.0)			T; T
Vegetative repro.	3.0**(.6) 0.3 (.3)	T; T	1.7 (.7) 0		0.7 (0.3) 0			0; 0
Fish Creek								
Height		19.5**(0.9) 9.32 (2.2)	12.1*(1.2) 0		0; 0			0; 0
Flowers		3 0	0; 0		0; 0			0; 0
% cover		76.7 (8.3) 37.0 (18.9)	1.2*(4.1) 0		0; 0			0; 0
Biomass		- ; -	34.9**(16.8) 0		0; 0			0; 0
Vegetative repro.		3 1	1.0 (1.0) 0		0: 0			0; 0

Continued...

Table 36.33. Continued.

	Arcta red fescue	Boreal creeping red fescue	Durar hard fescue	Nugget poa	Meadow foxtail	Slender wheat grass	Hair grass	Engmo timothy
Dall Summit								
Height	10.6*(0.9)	7.4*(0.5)	10.4*(1.4)	8.4(1.1)*	15.9*(1.6)	T; T	22.0**(3.4)	13.8*(2.5)
	5.1 (0.4)	4.5 (0.2)	3.4*(0.7)	3.8(0.5)	6.1*(1.0)		9.3 (3.1)	4.5 (0.4)
Flowers	81.4(54.3)	T; 0	27.8** (12.3)	64.6(33.0)	27.8** (12.3)	T; T	3	22.0 (12.3)
	0		0	0	0		0	0
% cover	40.0*(0.0)	46.7*(6.4)	31.7*(6.0)	23.3*(5.5)	11.7*(4.1)	T; T	45.0**(14.4)	25.0 (5.6)
	5.8*(2.8)	18.3*(5.0)	5.0*(2.8)	8.3 (3.6)	T		23.3 (1.3)	11.7 (4.1)
Biomass	147.9 (33.0)	107.9 (16.2)	101.4*(23.9)	71.1**(18.1)	60.7*(13.6)	T; T	-;-	67.2**(18.7)
	12.9*(2.6)	39.4*(7.8)	10.3 (4.5)	16.0(5.2)	16.5*(0.0)			16.8 (4.5)
Vegetative repro.	4.0** (0.0)	4.0*(0.0)	3.0 (1.3)	2.3**(0.3)	2.7*(0.3)	T; T	2	2.3**(0.3)
	1.7 (0.7)	4.0*(0.0)	1.0 (0.6)	0.7(0.3)	0		0	0.7 (0.3)
Anaktuvuk Pass								
Height			16.3*(1.1)	6.4*(0.5)	9.0**(1.3)	23.2**(2.4)		7.0**(0.9)
			4.4*(0.6)	3.1 (.5)	5.2 (0.8)	16.3 (1.2)		3.3 (0.4)
Flowers			286.2*(96.3)	416.7 (183.5)	0; 0	177.7 (48.5)		5.8 (5.2)
			0	0		4.3* (0.9)		0
% cover			25.0**(5.6)	23.8**(4.8)	13.3*(4.4)	20.0*(4.5)		6.7**(3.2)
			10.0*(4.0)	7.5*(4.2)	T	15.0 (4.0)		0
Biomass			189.3*(38.1)	155.0**(47.8)	31.0*(9.0)	131.8**(31.0)		32.4*(7.1)
			22.0 (9.0)	17.4 (7.8)	1.9 (1.3)	63.3 (11.0)		4.5 (2.6)
Vegetative repro.			4.0*(0.0)	3.0**(0.4)	1.3*(.3)	3.5*(.3)		1.3 (.3)
			0.7 (0.3)	1.0 (0.0)	0	1.3 (.3)		0.3 (.3)
Wiseman		12.3**(1.8)	30.5 (3.1)	15.8**(3.3)	43.8*(7.0)		25.4*(2.9)	41.9*(9.0)
Height		7.1 (1.0)	10.9 (4.8)	4.8 (0.3)	7.3 (1.7)		8.5 (1.7)	6.8 (1.5)

Continued...

Table 36.33. Continued.

	Arcta red fescue	Boreal creeping red fescue	Durar hard fescue	Nugget poa	Meadow foxtail	Slender wheat grass	Hair grass	Enemo timothy
Flowers		0;0	4	0;0	16.8 (11.6)		4	269.4*(89.8)
			0		0		3	27.1 (22.0)
% cover		63.3*(6.2)	91.7 (8.3)	-;-	33.3*(6.1)		18.3**(1.7)	23.3*(5.5)
		41.7 (6.4)	20.3 (17.4)		10.0 (3.9)		5.3 (2.6)	8.3 (3.6)
Biomass		253.9**(54.9)	-;-	-;-	419.3*(113.1)		-;-	823.7*(129.9)
		105.3 (29.1)			39.4*(17.4)			40.7 (14.9)
Vegetative repro.		4.0 (0.0)	4	-;-	3.7*(0.3)		0; 0	3.3 (0.7)
		27.7 (0.9)	2		1.0 (0.6)			1.3 (0.9)
Pump station 3								
Height				11.5*(1.5)		32.8*(2.5)		
				3.5 (0.3)++		7.6*(1.0)++		
Flowers				2.3*(0.6)		299.7*(58.1)		
				0		2.6 (1.9)		
% cover				28.8*(3.6)		10.6**(2.4)		
				3.1 (1.4)		5.0 (1.7)		
Biomass				68.5*(11.6)		129.9*(20.7)		
				5.2 (1.3)		7.8 (1.9)		
Vegetative Repro.				3.3*(0.4)		3.3 (.4)		
				0.8 (0.3)		0.3 (0.2)		
Galbraith Lake								
Height	13.8*(2.0)	<1; <1	8.8*(0.5)		0; 0	21.4 (5.6)	57.6*(3.4)	0; 0
	3.2 (0.6)		2.2 (0.4)			8.3 (0.6)	13.6 (1.7)	
Flowers	T; 0	T; 0	T; 0		0; 0	146.0 (89.8)	4	0; 0
						0	3	
% cover	50.0*(6.5)	T; 0	20.0*(5.2)		0; 0	5.0 (2.81)	100.0*(0.0)	0; 0
	3.3 (2.3)		1.7 (1.7)			0	12.3 (11.3)	

Continued ...

Table 36.33. Concluded.

	Arcta red fescue	Boreal creeping red fescue	Durar hard fescue	Nugget poa	Meadow foxtail	Slender wheat grass	Hair grass	Engmo timothy
Biomass	170.5*(32.3)	T; 0	37.5*(9.0)		0; 0	48.5 (26.5)	-;-	0; 0
	7.8 (3.2)		1.7 (1.7)			3.2 (1.9)		
Vegetative repro.	3.7*(0.3)	0; 0	2.0 (.6)		0; 0	1.7 (1.2)	4	0; 0
	0.3 (0.3)		0.3 (0.3)			0	1	
Hess Creek								
Height	22.1*(2.3)	24.7*(1.9)						
	8.4 (0.8)	10.9 (1.8)				0; 0		36.0(6.7)
Flowers	4	124.0* (34.2)						15.1 (3.8)
	3	21.3 (16.8)				0; 0		274.6 (97.6)
% cover	93.3**(4.4)	42.0* (6.0)						107.9 (43.9
	50.0 (12.6)	23.0 (5.0)				0; 0		18.3 (5.0)
Biomass	-;-	429.9* (93.0)						11.7 (4.1)
		228.0 (69.1)				0; 0		488.5 (181.5)
Vegetative repro.	4	4.0 (0.0)						158.9 (7.1)
	3	3.3 (0.3)				0; 0		2.7 (0.3)
								2.3 (0.3)

Source: Van Cleve (1977).

Note: Height, flowers, % cover, and biomass reflect only second season of growth; vegetative reproduction reflects accumulation of 2 seasons' growth.

* Difference between means significant at 1% level of probability.
† Mean ± standard error of mean for fertilized treatment (8-32-16).
‡ Mean ± standard error of mean for control.
$T = trace
- Parameter not tested, or species not tested at site.
Visual estimation of sod formation on scale 0-4 (none, poor, fair, good, excellent). Where flower counts could not be made, same scale was used.
** Difference between means significant at 5% level of probability.
++ Three-year data.

climatic adaptation and may be maintained only by constant fertilization.

Hernandez (1972, 1973b) reported on the results of a study conducted by R.W. Wein to determine the effects of fertilizers on revegetation of winter roads near Norman Wells and Tuktoyaktuk, N.W.T. A 1971/72 winter seismic line and trails bulldozed through native vegetation were used to simulate the road at Norman Wells. At Tuktoyaktuk, plots were established on the winter road used by Imperial Oil Ltd. to supply and move outlyings rigs from its Tuktoyaktuk base camp.

Both heavily disturbed (mineral soil exposed) and lightly disturbed areas (peat exposed) at each site were seeded in early June with the following:

1. Native Mix: Calamagrostis canadensis, Arctagrostis latifolia, Senecio congestus, Erechtites sp.
2. Agronomic Mix: Festuca rubra cv. Arctared, Poa compressa cv. Canon, Dactylis glomerata cv. Kall, Phleum pratense cv. Climax.
3. Total Mix: Mix of all eight species in (1) and (2) above.

Two levels of fertilizer were used: 0 and 100 kg/ha each of elemental nitrogen as ammonium nitrate (34-0-0) and phosphorus as superphosphate (0-20-0). There were 18 replicates seeded at Norman Wells and 13 at Tuktoyaktuk. Each replicate consisted of six 2 x 2 m subplots, seeded so that all species in a mix had approximately equal numbers of viable seed, as determined from germination tests. Total sowing intensity was 1000 viable seeds per m^2.

In late August, all plots were sampled. Cover, density and height were determined for each species wherever possible (Table 36.34 and 36.35). The native forbs, Erechtites and S. congestus could be easily distinguished from the grasses and are listed separately. Grasses were lumped together (except Phleum at Norman Wells) due to their size and low cover. In general, fertilizer resulted in

Table 36.34. Plant cover, density, and height for the three seed mixes and two fertilizer levels sown on two soil types on a winter road near Tuktoyaktuk, N.W.T. Data are given as means ± standard error for 45 quadrats (50 x 20 cm) on organic soil and 20 quadrats of mineral soil. Sampled 19 August, 1972.

Species		Soil Type[a]											
		Organic						Mineral					
		Treatment[b]											
		Nat 0	Nat 100	Agr 0	Agr 100	All 0	All 100	Nat 0	Nat 100	Agr 0	Agr 100	All 0	All 100
Marsh fleabane	C[c]	0.2±0.05	0.5±0.1			0.2±0.05	0.6±0.2	0.1±0.1	1.1±0.3			0.2±0.05	0.6±0.2
	N[d]	7±3	14±4			8±4	16±5	9±7	19±6			8±4	16±5
	H[e]	0.2±0.1	0.6±0.1			0.2±0.1	0.6±0.1	0.1±0.04	0.9±0.1			0.2±0.1	0.6±0.1
Fireweed	C	0.2±0.1	1.3±0.2	N.A.[f]		0.2±0.1	1.2±0.3	0.1±0.1	1.7±0.6	N.A.		0.2±0.1	1.2±0.3
	N	18±8	56±15			8±2	52±18	6±3	83±33			8±2	52±18
	H	0.2±0.1	1.0±0.1			0.3±0.1	1.0±0.1	0.1±0.1	1.0±0.2			0.3±0.1	1.0±0.1
Grasses	C	0.5±0.0	0.5±0.32	0.6±0.05	1.6±0.16	0.6±0.03	1.2±0.1	0.5±0.3	0.6±0.1	0.9±0.1	1.7±0.1	0.7±0.1	1.3±0.1
	N	45±5	57±7	140±22	179±24	96±13	144±20	76±17	78±10	210±29	163±20	180±43	124±16
	H	1.6±0.1	3.1±0.2	2.7±0.2	6.6±0.4	2.3±0.2	6.0±0.4	1.4±0.2	3.1±0.3	3.2±0.3	7.8±0.3	2.7±0.3	6.9±0.7

Source: Hernandez (1973b:117).

[a] Organic soil - Nine replicates (Reps 1 to 9 in Appendix A, Fig. 20) were established on exposed peat of the winter road proper passing through dwarf shrub-heath plant communities. Mineral Soil-Four replicates (Reps 10 to 13, Appendix A, Fig. 20) were established on a clayey sand heavily disturbed area off the road.

[b] Treatments: Nat - Native seed mix: tall arcticgrass, bluejoint, fireweed, marsh fleabane; Agr - Agronomic seed mix: Arctared creeping red fescue, Canada bluegrass, Climax timothy, Orchardgrass; all - Total mix of all eight species listed; 0 = no fertilizer; 100 = 100kg/ha of both elemental N and P.

[c] C - Cover (%)

[d] N - Number of plants/m^2

[e] H - Height (cm) to longest leaf or top of seed head

[f] N.A. - not sown

Table 36.35. Plant cover, density, and height for the three seed mixes and two fertilizers sown on three community-soil types on a 1971-72 winter seismic line and bladed trails to simulate a winter road near Norman Wells, N.W.T. Data are given as means ± standard error for 30 quadrats (50 x 20 cm) on each of a wet organic soil, a dry organic soil and a mineral soil. Sampled 30 August, 1972.

		Soil Type[a] / Treatment[b]																	
		Wet Organic						Dry Organic						Mineral					
		Nat 0	Nat 100	Agr 0	Agr 100	All 0	All 100	Nat 0	Nat 100	Agr 0	Agr 100	All 0	All 100	Nat 0	Nat 100	Agr 0	Agr 100	All 0	All 100
Marsh fleabane	C[c]	1.1±0.5	3.8±0.7			0.5±0.1	0.9±0.3	0.1±0.03	2.2±0.5			0.1±0.16	0.7±0.2	1.2±0.5	6.8±1.0			0.6±0.3	3.0±0.6
	N[d]	11±4	30±10			8±2	6±2	4±2	18±5			2±2	8±2	14±5	43±7			8±4	20±3
	H[e]	0.7±0.2	1.4±0.3			0.4±0.1	1.3±0.5	0.1±0.03	1.1±0.2			0.1±0.1	0.9±0.4	0.7±0.2	3.7±0.5		N.A.	0.3±0.1	2.6±0.5
Fireweed	C	0.8±0.2	6.1±1.0		N.A.	1.0±0.3	4.3±1.5	0.2±0.06	8.4±1.1		N.A.	0.1±0.05	5.7±0.8	0.3±0.1	7.1±1.7			0.1±0.1	6.3±1.0
	N	45±13	118±20			28±8	54±13	11±5	114±16			9±5	79±11	20±8	99±20			4±2	79±10
	H	0.4±0.1	2.5±0.6			0.4±0.1	3.0±1.1	0.2±0.06	3.8±0.6			0.1±0.05	3.8±0.7	0.3±0.1	4.8±1.4			0.1±0.1	7.0±1.1
Climax timothy	C			3.0±0.4	7.4±1.1	2.9±0.3	3.7±0.4			2.6±0.5	10.5±1.0	1.1±0.2	4.8±0.4			2.8±0.4	11.3±0.8	2.8±0.5	7.9±0.6
	N	N.A.		115±14	143±16	76±8	74±7	N.A.		101±14	163±15	63±11	108±9	N.A.		117±12	151±10	81±9	103±6
	H			5.5±0.6	21.7±2.8	8.5±1.0	15.2±3.4			5.5±0.8	30.1±3.0	3.0±0.3	17.5±1.7			7.5±1.0	37.5±2.9	7.2±0.8	34.8±2.6
Other Grasses	C	1.3±0.2	2.2±0.2	1.9±0.2	3.2±0.3	1.6±0.2	2.8±0.3	0.7±0.1	1.5±0.2	1.5±0.2	2.9±0.3	1.1±0.1	2.5±0.3	1.1±0.1	2.1±0.3	1.3±0.1	4.3±0.4	1.6±0.2	3.6±0.6
	N	95±9	141±17	136±23	172±28	149±19	144±15	56±11	76±9	188±31	133±14	111±17	108±11	119±22	103±11	134±21	108±13	130±15	103±9
	H	1.8±0.2	4.3±0.3	3.4±0.4	6.6±0.6	3.0±0.3	5.3±0.4	2.0±0.3	5.0±0.6	2.5±0.2	6.7±0.6	2.3±0.2	5.3±0.3	2.4±0.2	5.2±0.4	2.9±0.2	10.6±0.8	3.1±0.3	9.1±0.8

Source: Hernandez (1973b:118-119).

[a] Wet Organic Soil = six replicates were established on exposed wet peat through areas of tamarack-sedge; Dry Organic Soil = six replicates were established on exposed mesic peat through areas of black spruce-shrubs-heath forest. Mineral Soil = six replicates were established on exposed mineral soil through areas of black spruce-shrub-heath forest.

[b] Treatments: Nat = native seed mix: tall arcticgrass, bluejoint, fireweed, marsh fleabane; Agr = agronomic seed mix: Arctared creeping red fescue, Canada bluegrass, Climax timothy, Orchardgrass; All Total mix of all eight species listed; 0 = no fertilizer; 100 = 100 kg/ha of both elemental N and P.

[c] C = Cover (%)

[d] N = Number of plants/m^2

[e] H = Height (cm) to longest leaf tip or top of seed head

[f] N.A. = Not sown.

approximately a three-fold increase in plant cover and height for all mixes on all soil types at both sites. Establishment rates improved in most instances.

McKendrick and Mitchell (1978) found a marked growth response to a general purpose fertilizer in oil damaged vegetation near Prudhoe Bay, Alaska. Given these results, the authors set up plots to assess the effects of the individual nutrients at three levels (Table 36.36). Fertilizers were spread in early September 1973 and data on dry matter production taken in 1976 and 1977.

The most obvious response was a consistent and marked increase in growth of grasses and re-establishment of moss in plots fertilized with P (Table 36.36). Additions of N and K did not seem to visibly increase plant growth and recovery; K, in fact, appeared to significantly reduce yield.

Troth et al. (1973) studied the effects of nitrogen fertilization on grasses sown onto old oil spill sites along the Alaska pipeline. Two sites were chosen for study in 1972. One was a 1968 spill at Milepost 119 adjacent to Lake Dezadeash in the Yukon Territory. The second site was an older (1956) spill, also in the Yukon Territory, but near Lake Kluane at Milepost 207.6. Study plots were initiated in two areas at Milepost 119. The first area, once a mixed Alnus spp. and Salix spp. stand, was covered with a 10 cm layer of dead moss and organic material. The second area, once a mature Picea glauca stand, was covered with a 25 to 30 cm layer of dead moss and organic material. The location at pipeline Milepost 207.6, at one time a mature P. glauca stand, was also covered with a 25 to 30 cm mat of dead moss and organic material.

Lolium multiflorum, Bromus inermis, or Festuca rubra were applied separately to one third of each 1 m^2 plot. Fertilizer treatments, as commercial 20-10-10, were applied in two replicates at each location.

Treatments were applied on 19 June 1972 at Milepost 119, and on 20 June at Milepost 206.7 as follows:

Table 36.36. Average vascular plant dry-matter yields (g/m^2) for 1976 and 1977 under three fertilization rates (kg/ha) of N, P, and K, applied to oil-damaged wet tundra, Prudhoe Bay, Alaska.

Nitrogen		Phosphorus		Potassium	
Fertilizer rate	Dry-matter yield	Fertilizer rate	Dry-matter yield	Fertilizer rate	Dry-matter yield
0	45.8 a	0	15.1 a	0	54.7 b
86	43.0	75	61.9 b	143	35.3 a
172	41.0 a	150	65.4 b	286	30.7 a

Source: McKendrick and Mitchell (1978).

Note: Averages followed by the same letter within a column were not statistically different at the .05 level of probability according to Duncan's New Multiple Range test.

1. Pipeline Milepost 119. The same treatments were replicated in both the Alnus-Salix stand and the Picea stand.
   (1) Control; plot stripped of organic mat and seeded, without fertilizer.
   (2) 112 kg/ha N; plot stripped of organic mat, fertilized, and seeded.
   (3) 224 kg/ha N; plot stripped of organic mat, fertilized, and seeded.
   (4) Unstripped; fertilizer applied at 224 kg/ha N to the undisturbed surface of the organic mat. No seed was applied.
2. Pipeline Milepost 207.6
   (1) Control; plot stripped of organic mat and seeded without fertilizer.
   (2) 112 kg/ha N; plot stripped of organic mat, fertilized, and seeded.
   (3) 224 kg/ha N; plot stripped of organic mat, fertilized, and seeded.
   (4) 112 kg/ha N U; organic mat left undisturbed, plot fertilized, and seeded.
   (5) 224 kg/ha N U; organic mat left undisturbed, plot fertilized, and seeded.

Treatments were visually assessed for relative success or failure of vegetation establishment on 21 August 1972.

At Milepost 119, grass establishment and growth was fairly good on both sites without fertilizer, but was visually improved by the addition of 112 kg/ha N. The addition of 224 kg/ha N provided no additional benefit. There was no growth where fertilizer was placed directly on the unstripped plot.

At Milepost 207.6, the response of the seeded species to 112 kg/ha of fertilizer was somewhat better than with no fertilizer but

the 24 kg/ha treatment had the poorest growth. Where the dead organic mat was not removed there was some new growth; the 224 kg/ha treatment gave better results than 112 kg/ha.

From these studies Troth et al. (1973) stressed the importance of removing the dead organic mat to expose mineral soil, and noted that 112 kg/ha of N appeared to produce better growth than 224 kg/ha.

Several authors have reported on a series of revegetation studies carried out in the Mackenzie Valley and High Arctic (Younkin and Friesen 1976; Younkin and Martens 1976; Dabbs, Friesen and Mitchell 1974; Hernandez 1972; Babb 1973). The areas under study were chosen because they resembled areas along the proposed Mackenzie Valley gas pipeline. The studies are complex and the reader is encouraged to obtain the papers for further information.

Younkin and Friesen (1976), and Dabbs, Friesen and Mitchell (1974) studied the effects of fertilization on grasses sown at the Sans Sault test facility near Norman Wells, N.W.T. During the winter of 1970/71, four experimental test sections of 121.9 cm pipe were installed for the purpose of testing the engineering concept of a winter constructed, buried, and chilled natural gas pipeline. All trees and shrubs over 0.6 m high were hand cleared and the slash piled in a windrow at the periphery of the clearing. Gravel was back-loaded onto the windrow of trees to build a narrow roadway.

All pipeline ditching and construction activities took place on top of packed snow in December, January, and February. The material taken from the ditch was dumped on the snow, pipe installed, and the backfill returned to the ditch. Due to the bulking up of the soil when removed from the ditch in a frozen state, and the fact that a 1.2 m diameter pipe had been placed in the ditch, a mound or berm of material was left over the line. With subsequent thawing and compaction of the top layers, the berm receded to less than 0.6 m above grade. The net result of this construction technique was that the low shrubs, moss, and ground litter was left undisturbed except for the actual backfill mound and part of the spoil not returned to the ditch.

On 19 and 20 June 1971, Test Sections I, II, III, and IV were seeded. Each 152 m buried test section was marked off into 20 equal plots measuring 7.6 x 24.4 m with the pipeline running through the centre of the plot. The central 18 plots (outside plots seeded to a buffer zone mix) were each subdivided into "a" and "b" subplots.

The grasses seeded were selected by an agricultural consultant retained by ARCO Chemical Company at Fairbanks, Alaska. The common and scientific names of these 18 grasses, and the rates at which they were seeded, are given in Table 36.37.

The seed was pre-weighed and applied evenly over the entire plot (0.02 ha) using a hand-operated broadcast spreader. The fertilizer was spread after the seed was sown, using the same technique. Subplot "a" received fertilizer at a rate equivalent to 785 kg/ha and subplot "b" at a rate equivalent to 392 kg/ha of the formulation 10-19-19. A detailed analysis of the fertilizer was presented in the report, noting the presence of micronutrients in the mix.

To simulate construction conditions, no seed-bed preparations were made and no post-seeding treatments were applied. The seed and fertilizer were broadcast on the ground surface and not protected from predation or adverse climatic conditions.

Results from the first season's growth indicated that one third of the species required the high level of fertilization for maximum growth; however, no data were presented.

The plots on the active pipeline test sections were fertilized at the time of seeding in June of 1971 with as much as 70 kg/ha nitrogen. By late July 1972, many varieties showed signs of chlorosis. To determine if it was a nutrient deficiency, and to identify the deficiency, fertilizer was applied to 1 m^2 subplots within the major plot. The formulations 34-0-0 and 11-48-0 were applied at the equivalent of 400 kg/ha on 25 July 1972 to several plot in each test section.

Plots fertilized in July were sampled for biomass in August; all others were sampled in July. Data on litter, cover, survival, and growth of the grasses were collected and t-tests were used to compare

Table 36.37. Grasses seeded in Sans Sault fertilization trials, N.W.T.

Common Name	Botanical Name	Seeding Rate (kg/ha)
Brown Top	Agrostis tenius	11.2
Creeping Bent	A. palustris	11.2
Red Top	A. alba	44.8
Canada Bluegrass	Poa compressa	56.1
Fowl Bluegrass	P. palustris	33.6
Kentucky Bluegrass	P. pratensis	33.6
Rough Bluegrass	P. trivialis	33.6
Creeping Red Fescue	Festuca rubra	56.1
Meadow Fescue	F. elatior	33.6
Reed Fescue, Alta Fescue	F. arundinacea	33.6
Sheep Fescue	F. ovina	56.1
Meadow Foxtail	Alopecurus pratensis	33.6
Reed Canary Grass	Phalaris arundinacea	33.6
Crested Wheatgrass	Agropyron cristatum	33.6
Intermediate Wheatgrass	A. intermedium	33.6
Slender Wheatgrass	A. trachycaulum	33.6
Streambank Wheatgrass	A. riparium	33.6
Tall Wheatgrass	A. elongatum	33.6

Source: Adapted from Dabbs, Friesen and Mitchell (1974).

the effects of the two fertilization rates. The reader should refer to the paper for further details. Results were inconsistent among the four test sections of pipe, making general conclusions very difficult. Survival appeared to be affected by fertilizers, more than litter or ground cover, though the significance of the latter was only assessed on two test sections. The authors have also presented data on percent cover of invading species established on the exposed mineral soil. These data are highly variable among plots and test sections.

The response to the second application of fertilizer was assessed in terms of shoot biomass production. Nineteen out of 25 plots showed improved growth; thirteen of the 19 had best growth when treated with the 34-0-0 fertilizer (Table 36.38).

Younkin and Friesen (1976) studied the effects of refertilizing plots in Test Sections I to IV in June 1973. Commercial fertilizers (34-0-0, 11-48-0, 11-55-0, and 0-0-62) were used to prepare five mixes having ratios of 2:2:1 (N, P_2O_5, K_2O), 2:1:1, 1:2:2, 1:2:1, and 1:1:0, where 1 and 2 represent rates of 50 and 100 kg/ha, respectively. Each of the 125 randomly placed 1 m^2 quadrats within Test Sections II, III, and IV were refertilized with one of the five mixes, each mix therefore being represented by 25 quadrats.

In Test Section I half of each plot was refertilized with 500 kg/ha of 20-20-10 mix providing 100, 100, and 50 kg/ha of N, P_2O_5, and K_2O, respectively.

Data on shoot production were collected in mid-August. Of the 18 species tested in Section I, 10 showed a significant improvement in shoot production (Table 21.12) when refertilized. The response of individual species varied widely from a 564% increase for Poa trivialis to a 17% decrease for Festuca rubra. Overall increase was 56% (significant at P 0.01).

The results of the refertilization trials in Test Sections II, III, and IV are summarized in Table 36.39. A Duncan's Multiple Range Test revealed that all fertilizer treatments, except 1:2:2, produced significantly more shoot growth than no refertilization. Increases over no refertilization ranged from 71% for 1:2:1 to 128% for 2:1:1, the

Table 36.38. Growth response to second fertilization, Sans Sault field trials, N.W.T.

Sec. No.	Plot No.	Biomass gm/m^2	Litter gm/m^2	Height (cm)
I	P-2	307.6	40.8	24 to 28
I	P-2, 34-0-0	403.2		38 to 42
I	P-2, 11-48-0	344.0		34 to 38
I	P-3	33.0	140.6	18 to 24
I	P-3, 34-0-0	163.2		26 to 30
I	P-3, 11-48-0	108.8		22 to 26
I	P-4	137.2	114.4	12 to 18
I	P-4, 34-0-0	131.2		18 to 24
I	P-4, 11-48-0	102.4		20 to 26
I	P-5	105.2	9.2	14 to 18
I	P-5, 34-0-0	273.6		36 to 40
I	P-5, 11-48-0	163.2		16 to 20
I	P-6	30.0	170.0	4 to 8
I	P-7	159.2	11.6	75 to 80
I	P-7, 34-0-0	348.8		80 to 90
I	P-7, 11-48-0	254.4		75 to 80
I	P-8	21.4	69.6	60 to 65
I	P-9	70.4	60.8	10 to 14
I	P-10	189.2	33.6	36 to 40
I	P-10, 34-0-0	204.8		40 to 44
I	P-10, 11-48-0	313.6		36 to 40
I	P-11	648.7	230.8	80 to 100
I	P-11, 34-0-0	532.8		80 to 100
I	P-11, 11-48-0	308.8		80 to 100
I	P-12	377.6	70.4	55 to 60
I	P-13	234.0	250.8	25 to 30
I	P-14	136.4	137.2	12 to 16
I	P-15	233.2	16.4	60 to 70
I	P-15,34-0-0	212.8		60 to 65

continued...

Table 36.38. Continued.

Sec. No.	Plot No.	Biomass gm/m^2	Litter gm/m^2	Height (cm)
I	P-15, 11-48-0	275.2		60 to 70
I	P-16	50.0	73.2	40 to 45
I	P-17	151.2	22.4	100 to 110
I	P-17, 34-0-0	177.6		100 to 110
I	P-17, 11-48-0	233.6		100 to 110
I	P-18	122.0	10.4	80 to 90
I	P-19	168.4	54.0	60 to 70
I	P-19, 34-0-0	316.8		60 to 70
I	P-19, 11-48-0	161.6		60 to 70
I	P-20	116.8	2.8	20 to 30
II	P-1	123.2	4.4	
II	P-2	231.2	8.8	18 to 25
II	P-2, 34-0-0	209.6		25 to 30
II	P-2, 11-48-0	160.0		20 to 25
II	P-3	92.0	128.8	35 to 40
II	P-3, 34-0-0	222.4		40 to 50
II	P-3, 11-48-0	156.8		40 to 45
II	P-4	93.2	71.2	15 to 20
II	P-5	179.6	40.0	40 to 45
II	P-6	58.0	140.0	5 to 10
II	P-7	232.8	38.8	80 to 85
II	P-7, 34-0-0	476.8		80 to 85
II	P-7, 11-48-0	379.2		
II	P-8	135.6	103.2	35 to 40
II	P-9	128.8	107.6	10 to 15
II	P-10	214.8	49.2	55 to 60
II	P-11	253.2	111.2	40 to 70
II	P-11, 34-0-0	278.4		40 to 45

continued...

Table 36.38. Continued.

Sec. No.	Plot No.	Biomass gm/m^2	Litter gm/m^2	Height (cm)
II	P-11, 11-48-0	188.8		
II	P-12	208.0	66.8	35 to 45
II	P-12, 34-0-0	158.4		35 to 40
II	P-12, 11-48-0	94.4		20 to 25
II	P-13	186.0	175.6	35 to 40
II	P-14	114.8	88.4	15 to 20
II	P-15	217.2	85.2	60 to 70
II	P-15, 34-0-0	302.4		55 to 60
II	P-15, 11-48-0	534.4		55 to 60
II	P-16	160.0	54.8	75 to 80
II	P-17	187.6	86.8	90 to 100
II	P-17, 34-0-0	219.2		90 to 100
II	P-17, 11-48-0	156.8		90 to 100
II	P-18	283.2	33.2	100 to 110
II	P-19	185.2	118.0	50 to 55
II	P-19, 34-0-0	292.8		55 to 60
II	P-19, 11-48-0	172.8		45 to 50
II	P-20	213.2	102.4	
III	P-1	179.6	86.0	30 to 35
III	P-2	514.4	40.8	
III	P-3	182.8	95.6	50 to 55
III	P-3, 34-0-0	315.2		50 to 55
III	P-3, 11-48-0	344.0		55 to 60
III	P-7	448.4	25.6	110 to 120
III	P-7, 34-0-0	180.8		110 to 120
III	P-7, 11-48-0	305.6		110 to 120
III	P-11	122.0	85.6	35 to 40
III	P-11, 34-0-0	273.6		40 to 45

continued...

Table 36.38. Concluded.

Sec. No.	Plot No.	Biomass gm/m^2	Litter gm/m^2	Height (cm)
III	P-11, 11-48-0	144.0		35 to 40
III	P-15	130.4	36.4	40 to 50
III	P-15, 34-0-0	235.2		45 to 50
III	P-15, 11-48-0	150.4		40 to 50
IV	P-1	93.2	27.2	
IV	P-2	422.2	9.6	25 to 30
IV	P-2, 34-0-0	384.0		34 to 40
IV	P-2, 11-48-0	363.2		25 to 30
IV	P-3	295.2	13.6	55 to 60
IV	P-3, 34-0-0	401.6		55 to 60
IV	P-3, 11-48-0	472.0		55 to 60
IV	P-5	165.2	46.4	25 to 30
IV	P-5, 34-0-0	217.6		40 to 45
IV	P-5, 11-48-0	161.6		25 to 30
IV	P-7	272.0	76.4	30 to 40

Source: Dabbs, Friesen and Mitchell (1974).

Table 36.39. Mean shoot production (g/m^2 dry wt. ±S.E.) of refertilized and non-refertilized grasses growing over Test Section II, III, and IV at the Sans Sault Test Facility, N.W.T.

Refertilization treatment	Mean shoot production (±S.E.)[b]
Not refertilized[a]	224.6 ± 20.0 a
1:2:2	343.0 ± 50.0 a b
1:2:1	384.0 ± 42.7 b c
1:1:0	416.0 ± 54.2 b c
2:2:1	420.8 ± 46.4 b c
2:1:1	511.3 ± 54.3 c

Source: Adapted from Younkin and Friesen (1976).

[a] Fertilizer codes represent the composition of weight of N, P_2O_5 and K_2O; 1 equals 50 kg/ha and 2, 100 kg/ha.

[b] Any two means not followed by the same letter are significantly different at the 95% level.

larger increases coming from those fertilizer combinations high in nitrogen.

From these data Younkin and Friesen (1976) have concluded that refertilization stimulated significant increases in production, with fertilizers high in nitrogen resulting in the greatest growth response. They felt that if a heavy plant cover was required to maintain the integrity of a right of way, refertilization would be necessary, with the most suitable fertilizer being one high in nitrogen. They noted, however, that in areas of low erodibility the use of heavy seed and fertilizer applications was questionable as natural succession may provide adequate cover in time.

In a second series of experiments, Dabbs, Friesen and Mitchell (1974) set up twelve 1.5 m x 20 m plots on a winter road in 1972 to determine the effects of four rates of 24-24-0 fertilizer on a standard seed mix. The vegetation had been destroyed by use of tracked vehicles during the growing season.

The seed mix, applied at 30 kg/ha, was an equal mix, by weight, of Phalaris arundinarea, Phleum pratense cv. Climax, Secale cereale, Bromus sp., Festuca rubra, Agrostis alba, Trifolium hybridum and Medicago sativa. One of four rates of a 24-24-0 fertilizer was applied to each plot, replicated three times.

Younkin and Friesen (1976) summarized the data collected in the experiment, over four years, on the cover of living and dead seeded vascular plants, native vasculars, and bryophytes (Table 36.40). In the first season, cover improved significantly with the addition of fertilizer, the greatest cover coming from the highest level of fertilization. By the second season, the differences in fertilizer effects on seeded plants were less pronounced. The higher fertilizer levels improved the cover of invading native grasses and bryophytes. By the third season, there were no significant differences between any of the fertilizer rates. They concluded that though helpful in promoting rapid cover, initial high fertilizer rates were of little value over the long term.

Table 36.40. Mean ground cover (% ±S.E.) of seeded and native plants in response to increased rate of application of a 24-24-0 fertilizer, Norman Wells, N.W.T. Seed and fertilizer were applied in June 1972.

Ground Cover	Fertilizer Rate (100's kg/ha)	Percent Cover 1972	1973	1974	1975
Seeded Vasculars	0	16.4 ± 4.1 a	11.3 ± 2.6 a	14.7 ± 4.5 a	8.8 ± 2.1 a
	1	31.9 ± 5.4 b	19.3 ± 3.8 a b	12.4 ± 2.9 a	16.6 ± 3.5 a
Living	2	32.5 ± 4.2 b	21.6 ± 3.5 b c	14.8 ± 3.0 a	12.0 ± 0.7 a
	3	50.5 ± 5.0 c	29.7 ± 2.8 c	15.2 ± 3.0 a	15.9 ± 1.9 a
	0		0.3 ± 0.1 a	9.8 ± 2.5 a	13.9 ± 4.2 a
Dead	1		1.3 ± 0.8 a	9.9 ± 5.2 a	22.1 ± 5.0 a
	2		0.8 ± 0.2 a b	9.6 ± 2.5 a	20.0 ± 3.8 a
	3		3.8 ± 1.4 b	17.8 ± 6.3 a	23.8 ± 4.0 a
Native Vasculars	0		0.7 ± 0.2 a	3.5 ± 0.6 a	2.8 ± 0.5 a
	1		0.8 ± 0.2 a	2.6 ± 0.7 a	3.8 ± 0.6 a
	2		1.6 ± 0.7 a b	3.8 ± 0.7 a	4.8 ± 0.6 a
	3		4.2 ± 1.5 b	4.9 ± 1.3 a	6.1 ± 1.7 a
Bryophyta	0	4.4 ± 1.5 a	2.0 ± 0.7 a	5.0 ± 1.1 a	8.0 ± 1.4 a
	1	15.9 ± 3.6 b	7.3 ± 2.4 a	8.6 ± 4.4 a	20.3 ± 7.1 a
	2	17.4 ± 3.2 b	7.2 ± 2.6 a	11.4 ± 3.1 a	16.3 ± 5.1 a
	3	37.3 ± 3.7 c	15.5 ± 3.3 b	13.2 ± 4.3 a	18.9 ± 5.1 a

Source: Adapted from Younkin and Friesen (1976).

Note: Means in columns not followed by the same letter are significantly different according to Duncan's Multiple Ranges Test.

Younkin and Martens (1976) studied the effects of refertilization on grasses at two low arctic drilling sites. The first rig site, Gulf Mobil A-01, located south-east of Reindeer Station, N.W.T., was abandoned in 1971. The sump, still partially filled with water, was situated beside a large fan-shaped disturbed area on which all peat and vegetation has been removed down to the mineral soil. Seed and fertilizer were applied with a cyclone seeder in late June 1973. Rain had fallen during the preceeding three days, so that although it was rather late in the season, there appeared to be adequate moisture for seeding establishment.

Fourteen transects 30.5 m x 3.5 m spaced 1.5 m apart were established parallel to the disturbed slope. All transects except the two controls received a 14-28-14 fertilizer treatment of N, P_2O_5, and K_2O at 112 kg/ha. Treatments of Phleum pratense cv. Engmo, Festuca rubra cv. Arctared, Poa pratensis cv. Nugget, and the seed mixture (containing Poa pratensis cv. Nugget, Festuca rubra cv. Boreal, Phleum pratense cv. Climax, Phalaris arundinacea cv. Frontier, and Secale cereale cv. Prolific in the ratio of 2:2:2:1:1) were applied at rates of 28, 56, and 112 kg/ha. In June 1975, each treatment plot was divided into two subplots, one of which was refertilized with the same 14-28-14 mix at 280 kg/ha.

Cover and biomass data were collected in August 1975 for three species and the seed mix. Refertilization did not significantly increase seeded cover in the test plots (Table 36.41). The native vascular plants showed positive response to refertilization only in those plots where established cover of agronomics was low.

Refertilization improved biomass production of P. pratensis at all seeding rates, with the greatest increase in production occurring on plots with the lower seeding rates (Table 36.42). Younkin and Martens (1976) did not indicate if these increases were significant. Response in the F. rubra cv. Arctared plots was much smaller. Refertilization did not significantly affect the production of seed heads for either of these species.

Table 36.41. Effects of refertilization on cover of seeded and native vascular species on an abandoned drilling rig site near Reindeer Station, NWT.

	Seeding Rate kg/ha	Seeded		Native Vasculars	
		1975		1975	
		Not Refert.	Refert.	Not Refert.	Refert.
Control 1		0.2±0.2	0	42.6±2.4	56.0±3.4
Control 2		0.1±0.1	0	7.6±0.7	9.2±1.0
Mean		0.15±0.15	0	25.1±1.6	32.6±2.2
Seed Mix	28	77.5±4.1[a]	52.8±6.5[a]	6.2±0.7	15.8±1.6
	56	20.2±8.2	79.2±7.0	45.4±3.8	38.7±2.1
	112	48.0±7.4	70.0±6.5	25.0±3.0	17.9±2.7
Mean		48.6±6.6	50.7±6.6	25.5±2.5	24.1±2.1
Engmo timothy	28	0.1±0.1	1.6±0.5	30.9±2.6	39.3±2.5
	56	0.2±0.1	0.2±0.1	30.1±2.1	39.8±3.1
	112	0.1±0.1	0.8±0.3	18.6±1.5	26.0±1.5
Mean		0.1±0.1	0.9±0.3	26.5±1.7	35.0±2.4
Nugget Kentucky Bluegrass	28	78.6±6.6	87.5±0.0	0.2±0.2	2.1±0.5
	56	58.3±10.7	85.0±2.5	4.6±0.8	2.4±0.5
	112	85.0±2.5	82.5±3.3	1.5±0.5	1.7±0.5
Mean		74.0±6.6	85.0±1.9	2.1±0.5	2.1±0.5
Arctared Creeping Red Fescue	28	75.0±5.6	82.5±3.3	3.8±1.2	0.2±0.0
	56	67.8±8.8	85.0±2.5	4.9±1.0	0.0±0.0
	112	72.5±6.7	85.0±2.5	0.0±0.0	1.5±0.5
Mean		71.8±7.0	84.2±2.8	2.9±0.7	0.6±0.2

Source: Adapted from Younkin and Martens (1976).

[a] Less than 1% seeded cover provided by the timothy, reed canary, spring rye component of the seed mix.

Table 36.42. Mean oven dry weight (g/m^2 ±S.E.) of above ground biomass in refertilized and unrefertilized Poa pratensis cv. Nugget and Festuca rubra cv. Arctared plots on rig site A-01, N.W.T.

Seed Treatment	Seeding Rate (kg/ha)	Not Refertilized	Refertilized (280 kg/ha)
Arctared Creeping Red Fescue	28	938.6 ± 70.2	791.3 ± 77.9
	56	764.3 ± 78.1	1061.0 ± 67.6
	112	810.0 ± 70.8	920.0 ± 46.9
Nugget Kentucky Bluegrass	28	585.8 ± 84.6	913.0 ± 57.4
	56	679.8 ± 94.9	1068.6 ± 91.0
	112	973.6 ± 30.5	1068.0 ± 124.0
MEAN		792 ± 74.3	970 ± 81.4

Source: Adapted from Younkin and Martens (1976).

The second site was established on an abandoned rig site (IKHIL I-37) adjacent to Peter Lake, N.W.T. The study site had been abandoned during the winter of 1973. Much of the area was reasonably level, and all vegetation and root stocks had been removed. The remaining soil had a high organic matter content. All plots received a 14-28-14 fertilizer treatment of N, P_2O_5, and K_2O at 390 kg/ha.

Two seed mixes were sown, one made up of a complex 2:2:2:1:1 mix of Poa pratensis cv. Nugget, Festuca rubra, cv. Boreal, Phleum pratense cv. Climax, Phalaris arundinacea cv. Frontier, and Secale cereale cv. Prolific, and the other being a simple mix containing two components of the complex mix, Poa pratensis cv. Nugget and F. rubra cv. Boreal, in a 1:1 ratio. The 1:1 mix was sown at 28 and 56 kg/ha while the other mix was sown at 56 and 112 kg/ha.

Each combination of mix and rate was replicated four times. The seed and fertilizer were broadcast using cyclone seeders. No attempt was made to prepare or improve the seed-bed. Although there appeared to be adequate subsurface moisture, the soil surface was quite dry. On 01 June 1975, one half of each plot was refertilized with a 14-28-14 fertilizer at a rate of 280 kg/ha.

Cover was estimated in late August 1975. Refertilization of the simple mix did not stimulate cover production at either seeding rate. Total cover of the complex mixture was increased by refertilization especially at the lower seeding rate (Table 36.43). Cover of all components of the mix was increased. The Poa and Festuca component appeared to obtain the greatest benefit from refertilization.

Hernandez (1972, 1973b) has summarized the findings from two experiments established by Younkin in 1970 at Inuvik and Tuktoyaktuk, N.W.T. Fertilizers were tested alone, and in combination with agronomic grasses on mineral and organic soils. In the first study, plots were seeded and fertilized in June 1970, and data on cover and height taken in August 1971 and 1972. By 1971, plant growth (height) was significantly greater on plots given phosphorus (P, N + P, N + P + L). By 1972, there were no significant differences in cover among fertilizer treatments at Inuvik. At Tuktoyaktuk, however, cover of two of the

Table 36.43. Mean vegetative cover (% ± S.E.) in 1975 on plots seeded to a complex mixture in 1974 and partly refertilized in 1975, on abandoned rig site IKHIL I-37 near Peter Lake, N.W.T.

Species[a]	% Cover	
	Not Refertilized	Refertilized
Total Mix[b]	17.2 ± 0.9	28.6 ± 1.1
Total Mix[c]	22.2 ± 1.0	26.5 ± 1.1

Source: Adapted from Younkin and Martens (1976b).
[a] Values are means of four reps
[b] Seeded at 56 kg/ha
[c] Seeded at 112 kg/ha

surviving species (P. pratensis cv. Nugget, F. rubra cv. Arctared) was significantly lower in the control and lime only plots than in the other plots (Table 36.44). The best treatment was an application of N and P. Agropyron trachycaulum responded in a similar manner on mineral soil but required N + P combined in order to establish on organic plots.

In the second experiment, plots were established in mid-June 1971 and sampled for cover and height in August 1972. Fertilization effects were variable, depending on species, soil type, and location. In general, the N + P treatment was better than P alone which produced more growth than the controls. At Tuktoyaktuk, the 100 kg/ha N plus 200 kg/ha P provided the greatest productivity on both soil types. At Inuvik, the 100 kg/ha N plus 200 kg/ha P treatment was best on the organic soil but the 100 kg/ha N plus 100 kg/ha P was best on mineral soils. Improvements in cover were detected only on organic soil at Tuktoyaktuk, with 100 N plus 100 P being the best treatments.

Babb (1973) studied the effects of N, P, and K additions to disturbed high arctic sites on Devon Island, N.W.T. Plots were treated in 1979 with N, P, and K alone and in combination at 56 or 336 kg/ha. Growth of Saxifraga oppositifolia and Dryas integrifolia in the beach ridge plots and of Carex stans in the meadow plots was measured. Flowering of the Dryas and Saxifraga plants was also examined.

Data indicated that additions of N, P, and NPK at both rates improved plant production over controls for three seasons. Flowering in Dryas and Saxifraga, as well as other species was conspicuously stimulated. The author noted the improved growth due to addition of potassium, indicating that this result was not expected based on naturally high soil potassium levels. Babb also noted that large standard errors in the treated plots were attributable to microsite differences in fertilizer penetration and moisture availability.

On an abandoned gold and silver mine tailings pond near Carcross, Yukon Territory, Bayne (1975) studied the effects of fertilizers on establishment and growth of a seeded grass/legume mixture. Tailings at the Venus Mine were near neutral pH, low in nitrogen and phosphorus, and had moderate to low amounts of potassium.

Table 36.44. Mean cover rating (C)[a] and height (H)[b] in centimetres of species sown in mid-July at Tuktoyaktuk, N.W.T. on organic and mineral soil treated with different fertilizers. Data are given as means ± standard errors for three height measurements and one cover rating for each of three replicates per treatment. Data are presented only for the three species which survived in more than one treatment (sampled 19 August, 1972).

		Treatment[c] and Soil Type											
		Control		N		P		L		N+P		N+P+L	
		Organic	Mineral	Organic	Mineral	Organic	Mineral	Organic	Mineral	Organic	Mineral	Organic	Mineral
Nugget Kentucky bluegrass	C	2.5±0.5	0.3±0.3	3.5±0.5	1.7±0.3	3.5±0.5	3.3±0.3	2.0±0.0	1.7±0.7	5.0±0.0	4.7±0.3	4.5±0.5	3.7±0.3
	H	3.5±0.3	1.0±0.5	6.0±0.0[f]	4.0±0.5[f]	6.0±0.5[f]	5.3±0.2[f]	4.0±0.5[F]	4.0±0.3[f]	9.0±0.5[F]	13.3±1.0[F]	8.0±1.5[F]	14.0±1.1[F]
Arctared creeping red fescue	C	2.0±1.0	1.3±0.7	4.5±0.2	2.7±0.7	5.0±0.0	4.7±0.3	2.0±1.0	2.7±0.7	4.0±0.5	5.0±0.0	4.0±0.5	4.0±1.0
	H	7.0±1.5	3.7±0.9	11.5±0.9[f]	7.3±0.2[f]	13.0±1.0	12.0±1.1[F]	8.0±0.5	8.3±0.2	17.0±1.0[F]	35.8±4.2[F]	24.5±2.2[F]	42.7±8.2[F]
Slender wheatgrass	C	0	0.7±0.3	0	1.7±1.2	0	1.7±0.3	0	0.3±0.3	3.0±1.0	3.0±0.0	1.5±1.5	1.7±0.3
	H	0	5.3±1.5	0	17.0±5.1[f]	0	27.7±3.3[F]	0	5.0±2.5	31.0±4.0[F]	61.0±5.3[F]	12.0±6.0[f]	52.7±5.6[F]

Source: Adapted from Hernandez (1973b:93).

[a] Cover Rating classes (amount of row covered by plants): 0 - 0%; 1 - 1 to 10%; 2 - 11 to 33%; 3 - 34 to 67%; 4 - 68 to 95%; 5 - 96 to 100%.

[b] H - Height of plant to longest extended leaf or top of seed head.

[c] Treatments: N - nitrogen; P - phosphorus; L - lime. All applied at 100 kg/ha of element.

[F] Flowering abundant and greater than 5 seed heads/m of row.

[f] Flowers present at less than 5 seed heads/m of row.

Plots were hand raked to depth of 5.1 to 7.6 cm to break the surface crust and then seeded to a mix of 11 species at 448 kg/ha on 26 June. Six fertilizer treatments were assessed:

1. 10-30-10 at 2240 kg/ha plus lime at 1120 kg/ha.
2. 19-19-19 at 2240 kg/ha.
3. 19-19-19 at 1120 kg/ha.
4. 10-30-10 at 4480 kg/ha.
5. 10-30-10 at 2240 kg/ha.
6. 10-30-10 at 1120 kg/ha.

Treatments 1 and 6 provided best growth. Other treatments resulted in little growth response.

36.3 PLAINS REGION

McAllister Environmental Services (1978, 1979) reported on several studies at the Whitewood Mine, Alberta. In the first series of tests the authors varied nitrogen rates in an effort to determine the best application level for growing Hordeum vulgare on freshly levelled mine spoils. Fertilizers were applied as ammonium phosphate (11-55-0), urea (46-0-0), and potash (0-0-62). H. vulgare cv. Bonanza was seeded at 81 kg using a 15 cm row spacing.

In the first year Hordeum grain yields increased with each successive 17 kg/ha addition of N. The increase was lowest with the last addition of N, which the authors felt due to a phosphorus deficiency. For the second season, the fertilizer rates were increased in an effort to maximize yields; however, the treatment was ineffective. In the third season, N and K rates were increased slightly and Hordeum seeding rates were increased to 216 kg/ha. Hordeum vulgare cv. Betzes was sown instead of Bonanza. Grain yields increased 2 to 2.5 times with the increased levels of N (Table 36.45).

From these studies McAllister Environmental Services noted that N fertilization at 71 kg/ha produced Hordeum yields slightly above the regional mean yields (2256 kg/ha) when it was seeded at a rate of 215 kg/ha. Lower fertilizer or seeding rates produced yields much lower than the regional mean. The increase if N from 71 to 96 kg/ha did not

Table 36.45. Yield response of barley to varying rates of N-fertilization, Whitewood Mine, Alberta.

Yield (kg/ha)							
First Season[a]		Second Season[b]			Third Season[c]		
N	Grain	N	Straw	Grain	N	Straw	Grain
9	483	17	910	348	19	1048	1053
26	1235	34	1201	562	45	1809	2126
43	1719	67	2576	1413	71	2368	2757
59	1772	101	3018	1771	96	2701	2865
L.S.D.(5%)	150		251.3	138.1		285	335

Source: Adapted from McAllister Environmental Services (1978, 1979). Used by permission of TransAlta Utilities Corporation.

[a] P_2O_5 = 39 kg/ha, K_2O = 22 kg/ha
[b] P_2O_5 = 84 kg/ha, K_2O = 34 kg/ha
[c] P_2O_5 = 84 kg/ha, K_2O = 36 kg/ha

produce a significant yield increase. The change in Hordeum variety may also have affected yields.

In a second study McAllister Environmental Services planted Hordeum on land previously seeded to Medicago sativa for four years. Nitrogen was applied at two rates (19 and 75 kg/ha) while P was applied at 84 kg/ha P_2O_5, and K at 36 kg/ha K_2O. The higher level of N significantly increased grain yields, but only 7.5% over the lower level (Table 36.46). The authors felt that this demonstrated a reduction in crop reliance on N fertilization when following a Medicago sativa rotation.

In a third study the authors tested the effects of varying phosphorus levels on a forage/legume rotation. In the first season, only one of the four plots gave sufficient cover to sample for yields. Hordeum vulgare was seeded in this plot with three levels of phosphate. Nitrogen was applied at approximately 120 kg/ha and potassium was applied at 34 kg/ha. Grain yields increased significantly by increasing the P level to 56 kg/ha but not by the 112 kg/ha level (Table 36.47).

In the second season two plots were sampled. The first plot was seeded to Medicago sativa and Agropyron cristatum in the first season, and Hordeum in the second. Phosphorus was applied at three levels and N and K at 67 kg/ha, and 34 kg/ha (K_2O) respectively, in the second season. A significant yield increase was obtained with the addition of 56 kg/ha of P but not with a further increase of P (Table 36.48).

The second plot was seeded to Medicago and A. cristatum, in alternate rows, during the first season. Phosphorus and nitrogen were applied at three levels and potassium at 34 kg/ha in the first season. Due to the low survival of A. cristatum by the end of the first season, an additional 89 kg/ha of N and K_2O were applied in October. The yield of hay in the second season significantly improved with the increase of P from 28 to 56 kg/ha (Table 36.49). A further doubling of P rates did not significantly improve yields.

Table 36.46. Effect of N-fertilization of barley yields following four years of alfalfa, Whitewood Mine, Alberta.

Nitrogen (kg/ha)	Straw Yield (kg/ha)	Grain Yield (kg/ha)
19	4162	4006
75	3834	4335
L.S.D. 10%	302	302

Source: Adapted from McAllister Environmental Services (1979). Used by permission of TransAlta Utilities Corporation.

Table 36.47. Barley yield as affected by increasing phosphorus fertilization, Whitewood Mine, Alberta.

Phosphorus (P_2O_5) (kg/ha)	Nitrogen (kg/ha)	Straw Yield (kg/ha)	Grain Yield (kg/ha)
28	113	2344	1176
56	119	3080	1705
112	128	3435	1686
L.S.D. 5%		368	245

Source: Adapted from McAllister Environmental Services (1978). Used by permission of TransAlta Utilities Corporation.

Table 36.48. Barley yield as affected by increasing phosphorus fertilization, Whitewood Mine, Alberta.

Phosphorus (kg/ha) (P_2O_5)	Straw Yield (kg/ha)	Grain Yield (kg/ha)
28	1854	2008
56	2704	2567
84	2647	2703
L.S.D. 5%	313	309

Source: Adapted from McAllister Environmental Services (1979). Used by permission of TransAlta Utilities Corporation.

Table 36.49. Hay yields from an alfalfa/crested wheatgrass crop as affected by increasing phosphorus fertilization, Whitewood Mine, Alberta.

Phosphorus (P_2O_5) (kg/ha)	Nitrogen (kg/ha)	First Cut (kg/ha)	Second Cut (kg/ha)	Total (kg/ha)
28	111	4545	3086	7631
56	118	5625	3580	9205
112	127	5808	4048	9856
L.S.D. 5%		655	547	984

Source: Adapted from McAllister Environmental Services (1979). Used by permission of TransAlta Utilities Corporation.

From these studies McAllister Environmental Services concluded that grain and hay yields would reach an optimum with an input of 56 kg/ha phosphorus when seeding rates and nitrogen are adequate.

In early reclamation trials at Colstrip, Montana, Hodder (1971) studied the effects of fertilizers on the growth of Hordeum vulgare and Agroypron dasystachyum, sown in coal spoils, in the greenhouse, and in the field.

In the greenhouse study, five Hordeum plants were grown in pots filled with 1.2 kg of thoroughly mixed spoil material. Fertilizer was applied in all possible combinations of 0, 56, 112, and 168 kg/ha of available nitrogen (NO_3), phosphorus (P_2O_5), and potassium (K_2O).

In general, plants showed an increase in production with increased rates of fertilizer application; however, maximum production did not always occur at the highest rates.

In the field trial, plots were set up on a west-facing 3:1 slope in April. The plots had been seeded to A. dasystachyum cv. Critana the preceeding year. Fertilizer application rates are shown in Table 36.50.

Dry matter production of Agropyron increased up to 800% over the controls (Table 36.50) with increased fertilization. However, as in the greenhouse experiment, the greatest production did not occur with the highest rates. Potassium had little or no effect on Agropyron production. From these two studies Hodder noted that an application of 84 to 112 kg/ha N appeared optimum, while more testing on rates of P less than 180 kg/ha, was required.

Following this study, Sindelar, Hodder and Majerus (1973) tested three levels of N and four levels of P on the production of Triticum aestivum cv. Cheyenne at Colstrip. In April, a level area of spoils was chiselled and drill seeded to Triticum. Twelve fertilizer treatments (Table 36.51), each replicated three times, were randomly assigned to plots. Plots were fertilized with bucket universal spreaders on 05 May. Vegetation was clipped 23 August, the material oven-dried, and dry matter yield per square metre determined.

Table 36.50. Effects of 12 fertilizer treatments on thickspike wheat-grass seedling production at Colstrip, Montana.

Treatment	Production ($g/3m^2$)
$N_2P_2K_1$	154
$N_3P_2K_2$	135
$N_2P_2K_2$	133
$N_3P_2K_1$	119
$N_2P_1K_1$	54
$N_3P_1K_1$	37
$N_1P_2K_1$	34
$N_3P_1K_2$	33
$N_2P_1K_2$	33
$N_1P_2K_2$	27
$N_1P_1K_2$	21
$N_1P_1K_1$ (control)	20

Source: Adapted from Hodder (1971).

Note: N_1 = 0 kg/ha NO_3 N_2 = 84 kg/ha NO_3
P_1 = 0 kg/ha P_2O_5 P_2 = 179 kg/ha P_2O_5
K_1 = 0 kg/ha K_2O K_2 = 67 kg/ha K_2O
N_3 = 168 kg/ha NO_3

Table 36.51. Effects of 12 fertilizer treatments on production of winter wheat at Colstrip, Montana.

Treatment	Yield (g/m^2)
N_3P_4	78.96 a
N_2P_3	69.18 ab
N_2P_4	62.76 b
N_3P_3	61.88 b
N_2P_2	57.58 b
N_3P_2	56.84 b
N_1P_2	25.80 c
N_1P_4	25.26 c
N_1P_3	19.66 c
N_1P_1	16.56 c
N_2P_1	14.66 c
N_3P_1	11.52 c

Source: Adapted from Sindelar, Hodder and Majerus (1973).

Note: N_1 = 0 kg/ha; N_2 = 84 kg/ha; N_3 = 112 kg/ha

P_1 = 0 kg/ha; P_2 = 56 kg/ha; P_3 = 112 kg/ha; P_4 = 168 kg/ha

Values followed by the same letter are not significantly different at the 95% level of significance using Duncan's New Multiple Range Test.

Plant production increased with increasing amounts of fertilizer. The highest rate of application (112 kg/ha N and 168 kg/ha P) did not produce significantly more plant material than 84 kg/ha N and 112 kg/ha P, but was significantly better than all other treatments (Table 36.51).

The authors concluded that fertilization with both N and P was necessary at this site. The optimum rate for fertilizing T. aestivum was a combination of 84 kg/ha N and 112 kg/ha P.

DePuit, Coenenberg and Willmuth (1978) and Meyn, Sundberg and Young (1976) tested three fertilization rates on growth and yield of five cereal grains sown on raw spoils at Colstrip, Montana. Plots were ripped, disc plowed, cultipacked, and twice harrowed. The five grain species (Table 36.52) were planted with a Rangeland drill using a 30 cm row spacing. Fertilizer was broadcast at two rates, using a bucket spreader, in April.

Data on aboveground biomass were collected at the end of July. Best production of dry matter and seed of all species occurred with the lower fertilization rate (Figure 36.10). Meyn, Sundberg and Young noted that the lower production values, under the higher fertilization rate, may have been caused by the low level of precipitation during the growing season.

In the second growing season the same fertilizers were applied but only Hordeum vulgare, Avena sativa, and Triticum aestivum were seeded. Plots were fertilized 09 May and seeded 10 May. Production was measured on 08 August.

Aerial biomass production and seed yield of T. aestivum and Hordeum were highest under the maximum fertilization rate, while the lower fertilization rate again produced the best Avena crop (Table 36.53). The authors noted that the improved yields at the high fertilization rates may have been due to the fertilizer being applied prior to seeding, rather than one week later as in the first season, making more nutrients available to emerging seedlings. In addition, precipitation was higher in the second season, enhancing establishment and growth of plants.

Table 36.52. Species, seeding dates, and rates of cereals planted at Colstrip, Montana.

Species	Date Planted	Seeding Rate (kg/ha)
Barley	04 10 74	63
Oats	04 10 74	50
Spring Wheat	04 10 74	75
Winter Wheat	10 10 73	67
Speltz	18 10 73	56

Source: Adapted from Meyn, Sundberg and Young (1976).

Table 36.53. Mean aerial biomass and estimated grain yields for three cereal crops as affected by fertilization, Colstrip, Montana.

Species	Fertilizers					
	Aerial Biomass (kg/ha)			Seed Yield (kg/ha)[a]		
	0-0-0	45-56-22	90-121-45	0-0-0	45-56-22	90-121-45
Spring Wheat	170.7 a	1303.5 b	1540.8 c	59.1 a	467.3 b	547.9 b
Oats	19.2 a	248.4 c	122.2 b	21.5 a	311.5 c	150.4 b
Barley	81.8 a	1073.36	1548.2 c	43.0 a	553.2 b	794.9 c
Mean	90.6 a	875.1 b	1070.4 c	43.0 a	445.8 b	499.5 b

Source: Adapted from DePuit, Coenenberg and Willmuth (1978).
Note: Means in rows followed by the same letter are not significantly different at the 5% level by Duncan's Multiple Range Test.
[a] Calculated from seed-head weight data and an experimentally derived grain weight:seed-head weight ratio.

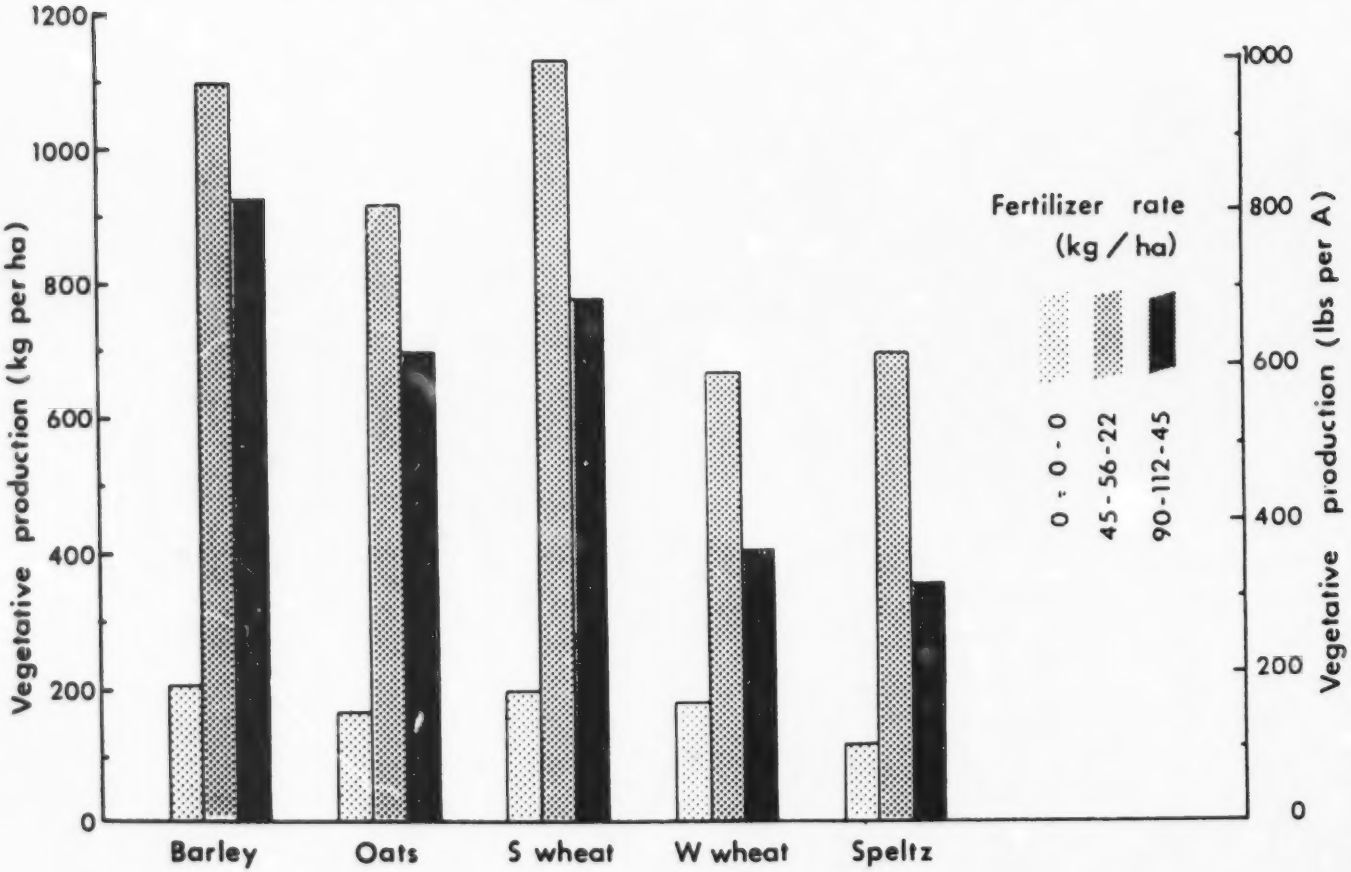


Figure 36.10. Variation in vegetative production of cereal grains planted at Colstrip in relation to three rates of fertilization, 1974.

Source: Meyn, Sundberg and Young (1976:29)

From the two years of data, Meyn, Sundberg and Young concluded that fertilization improved cereal crop yields on raw spoils but that yield improvements were species dependent, and timing of fertilization affected yields. They noted that although crops grew on raw spoils, even the highest yields there were poor when compared to unmined areas.

DePuit, Coenenberg and Willmuth (1978) studied the effects of varying nitrogen fertilizer levels on the success of a broad mixture of species sown into an established Wintergraze stand (G-4 Wintergraze; Triticum x Agropyron). In the spring of 1975, 12 plots were laid out to compare three fertilizer treatments: (1) F1 = 24 kg/ha actual N; (2) F2 = 52 kg/ha actual N; and (3) F3 = 80 kg/ha actual N. Phosphorus was applied to all plots as 32 kg/ha actual P. On 21 March, plots were chisel plowed to a depth of 2 cm, uprooting roughly one half of the Wintergraze. Plots were then uniformly broadcast seeded with a diverse mixture (Table 36.54) at 32.8 kg/ha bulk seed. Fertilizer was applied on 07 May.

Plant density data were collected in mid-June for two growing seasons. Cover, frequency, and plant biomass data were collected in the second growing season, also in mid-June.

There were no consistent trends in plant density with increasing fertilizer applications (Table 36.55), although legume and annual grass densities appeared depressed by the addition of fertilizers. Wintergraze, though supposedly an annual species, grew in both seasons and achieved greatest density under the medium fertilizer regime. The great increase in Salsola kali under all fertilizer regimes may be a factor to be considered. However, in later work S. kali responded in a similar manner then decreased drastically in the third year (DePuit and Coenenberg 1979). Data on plant cover and frequency in the second growing season followed the same pattern.

Legume biomass was significantly lower in the second growing season, under the two high-N fertilizers than under the low-N fertilizer (Table 36.56). Perennial grass biomass was significantly lower under the middle fertilizer level than under the high level. No other significant differences were found.

Table 36.54. Seed mixture used in Wintergraze Competition Study, Colstrip, Montana.

Scientific Name	Common Name	Bulk Seeding Rate(kg/ha)
Agropyron cristatum	Fairway crested wheatgrass	2.9
Agropyron dasystachyum (n)	Critana thickspike wheatgrass	2.9
Agropyron smithii (n)	Western wheatgrass	3.8
Agropyron elongatum	Tall wheatgrass	3.8
Bromus inermis	Lincoln smooth brome	2.9
Dactylis glomerata	Orchardgrass	1.9
Stipa viridula (n)	Green needlegrass	1.9
Medicago sativa	Ladak alfalfa	1.0
Astragalus cicer	Cicer milkvetch	1.9
Artemisia tridentata (n)	Big sagebrush	1.0
Calamovilfa longifolia (n)	Prairie sandreed	1.0
Oryzopsis hymenoides (n)	Indian ricegrass	1.0
Melilotus officinalis	Yellow sweetclover	1.0
Sarcobatus vermiculatus (n)	Greasewood	1.0
Purshia tridentata (n)	Bitterbrush	1.0
Onobrychis viciaefolia	Eski sainfoin	2.9
Triticum aestivum	Winter wheat	0.9
Total		32.8

Source: Adapted from DePuit, Coenenberg and Willmuth (1978).
Note: n = Native to Montana.

Table 36.55. Mean plant density (plants/m^2) under three fertilizer rates, Colstrip, Montana.

Plant Category	Fertilizer: First Season F1	First Season F2	First Season F3	Second Season F1	Second Season F2	Second Season F3
Grain (including Wintergraze)	89.6[a]	100.0	40.6	2.4	22.7	4.7
Perennial grasses	144.3	127.6	135.2	353.2	233.2	339.1
Annual grasses	4.4	2.1	1.0	6.3	2.4	0.8
Legumes	22.4	17.7	16.9	41.5	28.4	11.0
Forbs	4.9	2.9	6.3	0.8	3.2	0.8
Russian thistle[b]	28.7	29.5	47.2	1022.7	772.8	800.2
Total	294.3	279.8	247.2	1426.9	1062.7	1156.6

Source: Adapted from DePuit, Coenenberg and Willmuth (1978).

[a] Values are means of four replicates.

[b] Invading species.

Table 36.56. Aerial plant biomass as affected by three fertilizer levels, Colstrip, Montana.

Plant Category	Plant Biomass (kg/ha, dry-weight)[a,b] Fertilizer F1	F2	F3
Perennial grasses	782.7ab	547.6a	914.7b
Annual grasses	4.8a	6.4a	3.3a
Live grain[c]	6.3a	10.1a	4.8a
Legumes	636.7b	277.7a	223.8a
Forbs	1.8a	6.2a	2.1a
Russian thistle	371.7a	420.1a	238.5a
Total	1806.5b	1268.1a	1387.2ab

Source: Adapted from DePuit, Coenenberg and Willmuth (1978).

[a] Values are means of four replicates.

[b] Means in row followed by the same letter are not significantly different at the 5% level by Snedecor's Q test.

[c] Includes Wintergraze.

From these data DePuit, Coenenberg and Willmuth (1978) concluded that initial establishment of a seeded species mixture may be affected by fertilization rate. This was especially true for leguminous species which had lower establishment rates with increased fertilization. Since the medium fertilizer rate created overly vigourous stands of Wintergraze, which competed with seeded species, and as the heavy fertilizer rate may be economically unfeasible, the authors suggested using the lower rate to establish a satisfactory perennial grass and legume stand.

DePuit and Coenenberg (1979) set up a complex experiment near Colstrip, Montana to evaluate the effects of three rates of nitrogen fertilization, applied for one, two, or three years, on establishment and growth of a seeded grass/legume/shrub mixture. The reader is encouraged to obtain the publication for more details on experimental methods and results.

The site was ripped and approximately 15 cm of a fine sandy loam topsoil was applied. Subsoil was a loam to silt loam material. After settling, topsoil thickness was estimated at 10 cm.

The study was implemented as a split-plot (or nested) design of three blocks, two main plots within each block, and 12 subplots within each main plot. The main plots were randomly designated for seeding either in the spring or fall. All treatment combinations of four fertilizer rates and four durations of fertilizer application were randomly assigned to the 12 subplots in each main plot. The study site was drill seeded at 17 kg/ha to Triticum aestivum as a temporary stabilizer species in early November 1974 following disc plowing. On 17 November 1974 the plots designated for fall seeding were broadcast seeded with a mixture consisting of the same 16 native and introduced perennial grasses, legumes, and shrubs as in Table 36.54, excluding T. aestivum. Seeding rate for individual species was different than in 1975 but the total for all species was the same. The plots designated for spring seeding were similarly seeded on 25 March 1975. The spring-seeded plots were chisel plowed prior to seeding to relieve soil

compaction which had developed over the winter. Both fall- and spring-seeded plots were cultipacked following seeding.

The fertilization program was started after seedling emergence in June 1975 using properly mixed, prilled, commercial fertilizer. Nitrogen was applied at three rates in the form of ammonium nitrate (NH_4NO_3) and phosphorus at a constant rate as P_2O_5. Table 17.13 gives the fertilization program applied to the various treatments of the study. Because even the heavy 1975 P application rates had no appreciable effect on soil P levels, subsequent (1976 and 1977) P application rates were lowered.

Data on plant establishment were collected as seedling density in June 1975. Biomass measurements were obtained in late July 1976, 1977, and 1978. Plant cover and frequency were measured in early August 1976 and late July 1977 and 1978. Data are presented separately for each of the subexperiments (e.g., three fertilizer rates or three years of fertilization) for clarity. DePuit and Coenenberg noted that 1977 was marked by low spring precipitation and an extensive grasshopper defoliation problem (especially on legumes) which reduced many of the differences between treatments.

When comparing duration of fertilizer application, the authors found that biomass of perennial grasses in 1978 was greatest in plots receiving the full three years of fertilization (Table 36.57). In 1977, there were no differences in plots fertilized for one, two, or three years; however, fertilized plots had greater production than controls. Salsola kali, an invading species, had greatest production in 1976 in plots receiving two years of fertilizer. The species was barely present through subsequent years.

The production of legumes decreased significantly with the increasing number of fertilizer applications (Table 36.57, Figure 36.11). This decrease in production was due, in part, to competitive exclusion by perennial grasses such as Agropyron cristatum and Bromus inermis (Figure 36.12).

From this portion of the study, DePuit and Coenenberg concluded that while total aerial biomass was highest under three years

Table 36.57. Plant aerial biomass responses to duration of fertilization program, Colstrip, Montana, 1976 (all values means of all fertilizer application rate and season of seeding treatments and in kg/ha oven-dried weight basis.)

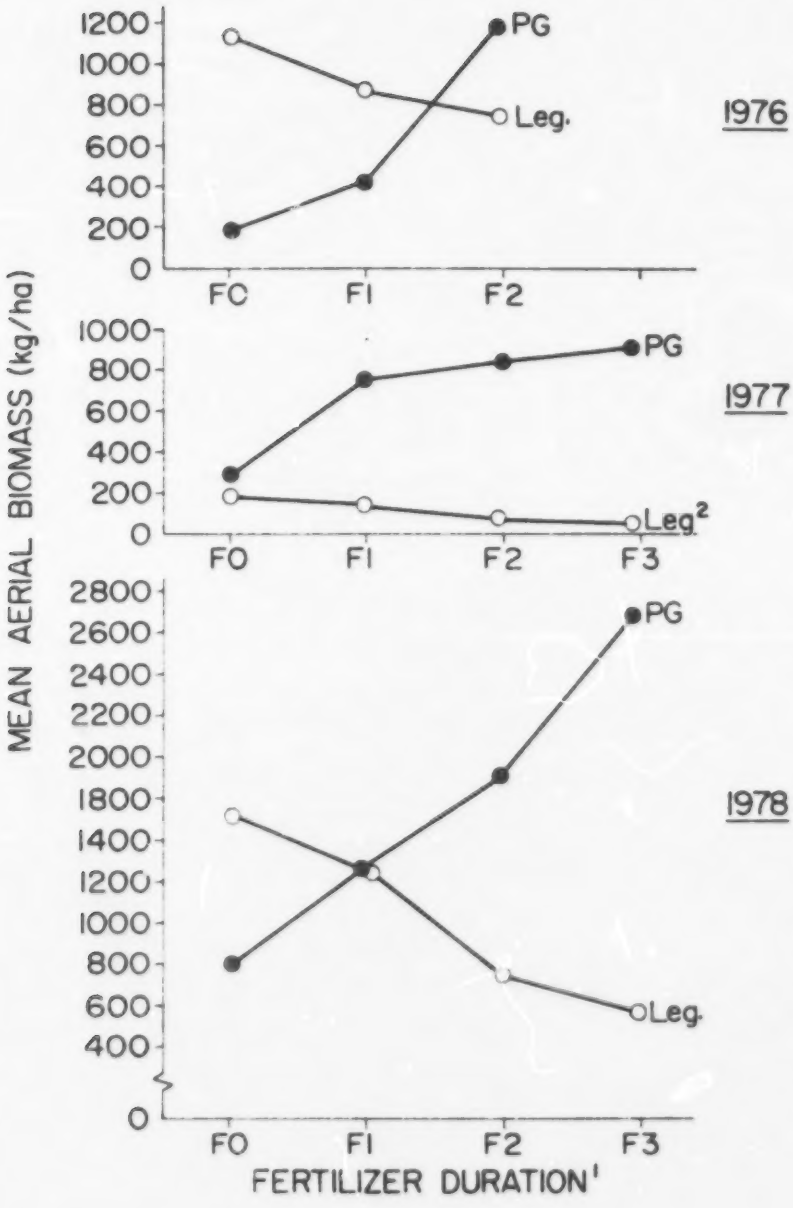
Plant class	Aerial biomass in: 1976[a] Plots not fertilized	Plots fertilized in 1975	Plots fertilized in 1975 & 1976	1977 Plots not fertilized	Plots fertilized in 1975	Plots fertilized in 1975 & 1976	Plots fertilized in 1975, 1976 and 1977	1978 Plots not fertilized	Plots fertilized in 1975	Plots fertilized in 1975 & 1976	Plots fertilized in 1975, 1976 and 1977
Perennial grasses	154c	399b	1199a	288b	764a	833a	928a	975d	1460c	1924b	2729a
Annual grasses	1	3	2	1	1	T	T	T	T	T	T
Legumes[b]	1151a	881b	741b	161a	125a	66b	33b	1712a	1430a	931b	755b
Forbs	1	3	2	3	1	1	1	3	3	T	T
Shrubs	ND	ND	ND	T[c]	ND	T	T	1	T	ND	T
Total non-thistle biomass	1307b	1286b	1944a	453b	891a	900a	962a	2691b	2893b	2855b	3486a
Russian thistle	219b	177b	481a	T	T		T	1		T	T
Total live biomass	1525	1463	2425	453	891	900	962	2692	2893	2855	3486
Standing dead biomass	400	340	701	} 1390	} 1511	} 2077	} 2426	220	352	420	400
Ground litter (mulch)	365	794	726					1151	1296	1686	1861

Source: DePuit and Coenenberg (1979)

[a] Values in rows during a given year followed by different letters significantly different at 5% level.

[b] Legumes biomass in 1977 drastically reduced from grasshopper defoliation.

[c] T = trace (<1 kg/ha)

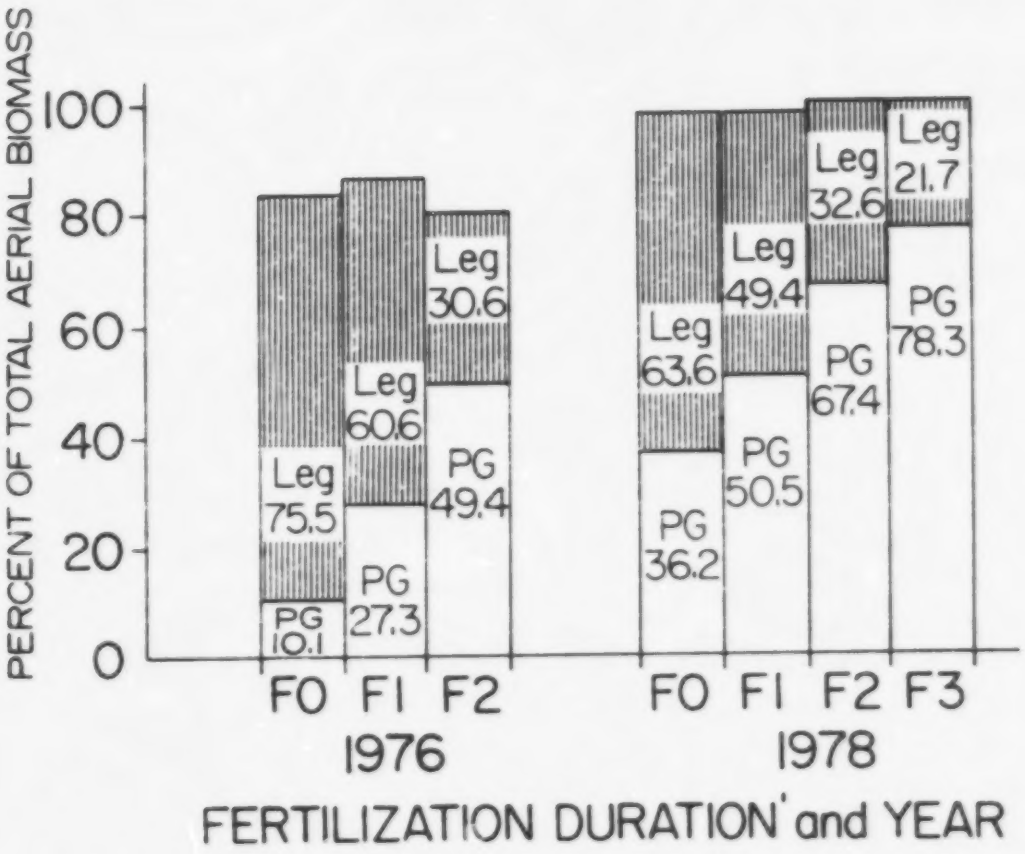


¹FO = not fertilized; F1 = fertilized in 1975 only; F2 = fertilized in 1975 and 1976; F3 = fertilized in 1975, 1976, and 1977

²1977 legume biomass drastically reduced by grasshopper defoliation

Figure 36.11. Graphic representation of perennial grass (PG) and legume (Leg) aerial biomass responses to duration (number of times of) fertilizer application, Colstrip, Montana, 1976 to 1978.

Source: DePuit and Coenenberg (1979a:34)



F0 = not fertilized; F1 = fertilized in 1975 only; F2 = fertilized in 1975 and 1976; F3 = fertilized in 1975, 1976, and 1977

Figure 36.12. Graphic representation of effects of fertilization duration on perennial grass versus legume stand composition, Colstrip, Montana, 1976 and 1978.

Source: DePuit and Coenenberg (1979a:38)

of fertilization, the community established had a low diversity index and a much smaller legume component than plots given fewer fertilizer applications. For this reason, they suggest that if a diverse plant community is the desired reclamation objective, then an initial fertilizer application may be all that is required.

When comparing fertilizer rates, they found that there were no significant differences in plant establishment between the three rates in the first year of this study. As in the previous study, there were significantly more legumes in the unfertilized plots than in the plots receiving the medium or heavy rate.

Assessment of the effects of fertilizer rates on biomass and cover in later years was based on the means of the three fertilizer duration treatments. By the fourth season (1978), biomass of perennial grasses was greatest in plots receiving the highest level of fertilizer (Table 36.58, Figure 36.13). As noted in the previous discussion, legume biomass was lowest in the plots receiving the most fertilizer. Table 36.59 demonstrates that cover of A. cristatum and B. inermis benefited most from the additional fertilizer. This increase in grass cover under the high fertilizer rate served to competitively exclude legumes from these plots (Figure 36.14).

From this portion of the study, DePuit and Coenenberg (1979) have concluded that increasing rates of fertilizer had no effect on plant establishment but increased productivity of perennial grasses significantly. Legume productivity decreased as a result of increasing fertilizer rates. They felt that the most desirable stand characteristics, in terms of productivity and diversity at the end of the fourth season (1978), were achieved in the plots receiving the low fertilizer rate (37 kg/ha N).

They noted that there were significant fertilizer rate/duration interactions in this study. Plots fertilized for the longest time period at the highest rates, had significantly greater perennial grass and significantly lower legume biomass (Table 36.60). The data in Table 36.61 show that although biomass increased with increased N

Table 36.58. Plant aerial biomass responses to fertilizer application rates, Colstrip, Montana, 1976 (value means of all fertilization duration and season of seeding treatments, and expressed in kg/ha oven-dried weight basis)[a].

Plant class	1976				1977				1978			
	Plots not fertilized	Plots fertilized at light[b] rate	Plots fertilized at medium[c] rate	Plots fertilized at heavy[d] rate	Plots not fertilized	Plots fertilized at light[b] rate	Plots fertilized at medium[c] rate	Plots fertilized at heavy[d] rate	Plots not fertilized	Plots fertilized at light[b] rate	Plots fertilized at medium[c] rate	Plots fertilized at heavy[d] rate
Perennial grasses	154c	678b	980a	1138a	288b	733a	894a	900a	975d	1670c	2003b	2440a
Annual grasses	1	1	3	2	1	1	T	T	T	T	T	T
Legumes	1151a	1153a	701b	510b	161[e]	100[e]	76[e]	48[e]	1712a	1440a	1071b	605c
Forbs	1	2	2	2	3	1	T	1	3	3	2	1
Shrubs	ND	ND	ND	ND	T[f]	T	ND	ND	1	T	ND	T
Total non-thistle biomass	1307b	1834a	1686a	1652a	453b	835a	970a	949a	2691b	3113a	3076a	3046a
Russian thistle	219b	270b	198ab	472a	T	T	T	ND	1	T	T	ND
Total live biomass	1526b	2104a	2084a	2124a	453b	835a	970a	949a	2692b	3113a	3076a	3046a
Standing dead biomass	400	411	548	783	1390	1492	2313	2209	220	369	424	380
Ground litter (mulch)	365	410	737	1100					1151	1391	1495	1957

Source: DePuit and Coenenberg (1979)

[a] Values in specific year rows followed by different letters significantly different at 5% level.

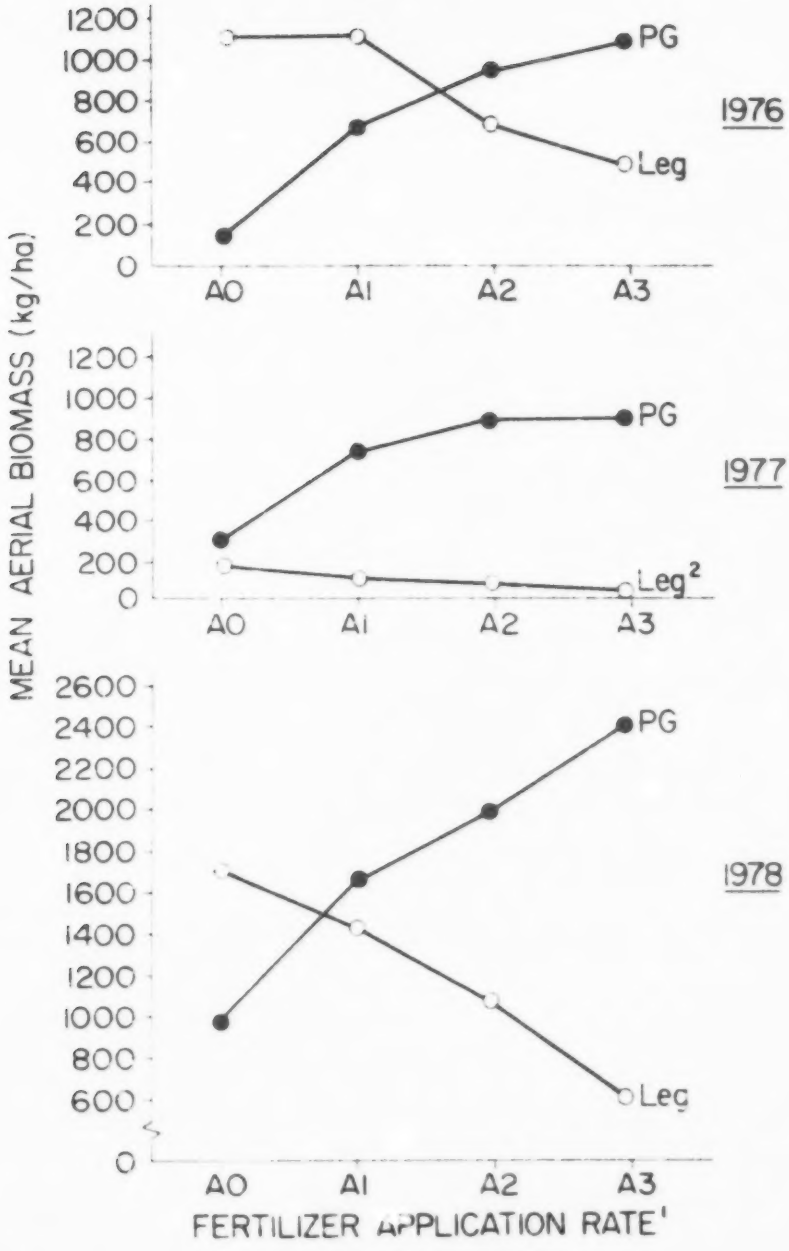
[b] Light rate = 37 kg/ha avail. N, avail. P = 41 kg/ha in 1975 and 11 kg/ha in 1976 and 1977, no applied K_2O; all plots fertilized in 1975, 2/3 in 1976, and 1/3 in 1977.

[c] Medium rate = 74 kg/ha avail. N, avail P = 41 kg/ha in 1975, and 11 kg/ha in 1976 and 1977, no applied K_2O; all plots fertilized in 1975, 2/3 in 1976, and 1/3 in 1977.

[d] Heavy rate = 121 kg/ha avail. N, avail. P = 41 kg/ha in 1975 and 11 kg/ha in 1976 and 1977, no applied K_2O; all plots fertilized in 1975, 2/3 in 1976 and 1/3 in 1977.

[e] Legume biomass in 1977 drastically reduced from grasshopper defoliation.

[f] T = trace (<1 kg/ha).



¹A0 = not fertilized; A1 = light rate; A2 = medium rate; A3 = heavy rate

²1977 legume biomass drastically reduced by grasshopper defoliation

Figure 36.13. Graphic representation of perennial grass (PG) and legume (Leg) aerial biomass responses to fertilizer application rate, Colstrip, Montana, 1976 to 1978.

Source: DePuit and Coenenberg (1979a:48)

Table 36.59. Plant canopy cover responses to fertilizer application rate, Colstrip, Montana, 1976-1978 (all values in percent and means of all fertilization duration and season of seeding treatment).

Plant species/class	1976				1977				1978			
	Plots not fertilized	Plots fertilized at light rate	Plots fertilized at medium rate	Plots fertilized at heavy rate	Plots not fertilized	Plots fertilized at light rate[a]	Plots fertilized at medium rate[b]	Plots fertilized at heavy rate[c]	Plots not fertilized	Plots fertilized at light rate[a]	Plots fertilized at medium rate[b]	Plots fertilized at heavy rate[c]
Perennial grasses:												
Agropyron spp[d]	-	0.1	0.1	0.2	nd	nd	nd	nd	5.0	2.8	2.4	2.2
Agropyron cristatum	6.8	17.4	22.6	29.1	8.8	26.1	30.1	28.4	22.1	44.9	49.4	60.6
Agropyron elongatum	2.5	3.4	4.2	2.9	3.3	4.4	3.6	2.7	6.4	5.5	5.7	4.3
Agropyron smithii	0.5	1.0	2.0	1.3	0.2	0.2	0.2	0.3	1.8	0.8	1.2	1.3
Bromus inermis	0.8	2.2	2.9	9.2	2.3	4.6	4.4	4.5	6.5	11.0	13.4	12.2
Calamovilfa longifolia	nd[f]	nd	nd	nd	nd	nd	nd	nd	0.6	0.1	-	-
Dactylis glomerata	0.3	2.8	2.4	1.4	0.1	0.2	0.1	T[h]	0.1	0.5	0.3	0.1
Oryzopsis hymenoides	nd	nd	nd	nd	nd	nd	nd	nd	4.4	1.9	1.8	1.4
Stipa comata	nd	nd	nd	nd	nd	nd	nd	nd	2.2	0.7	0.9	1.1
Stipa viridula	7.6	10.2	13.7	12.9	17.0	19.3	19.3	21.2	24.3	17.0	20.0	18.1
Undifferentiated	1.6	1.8	2.2	2.4	6.0	2.7	3.9	4.2	-	-	0.1	-
Total perennial grasses[e]	na[g]	na	na	na	34.4	50.5	53.7	54.7	58.1	69.0	76.9	84.0
Annual grasses:												
Bromus japonicus	0.1	T	0.2	0.1	0.1	0.3	0.1	0.1	0.1	T	-	0.1
Bromus tectorum									T	0.2	T	T
Total annual grasses[e]	0.1	T	0.2	0.1	0.1	0.3	0.1	0.1	0.1	0.2	T	0.1

Continued

Table 36.59. Concluded.

Plant species/class	1976				1977				1978			
	Plots not fertilized	Plots fertilized at light[a] rate	Plots fertilized at medium[b] rate	Plots fertilized at heavy[c] rate	Plots not fertilized	Plots fertilized at light[a] rate	Plots fertilized at medium[b] rate	Plots fertilized at heavy[c] rate	Plots not fertilized	Plots fertilized at light[a] rate	Plots fertilized at medium[b] rate	Plots fertilized at heavy[c] rate
Legumes:												
Astragalus alpinus	31.6	19.0	7.5	4.9	14.7	7.7	4.1	2.1	66.5	39.2	26.0	16.2
Medicago sativa	3.1	3.2	3.0	2.8	0.2	0.7	0.3	0.3	10.2	26.1	19.2	15.0
Melilotus officinalis	32.2	33.8	14.9	13.5	-	-	-	0.3	0.4	0.2	0.2	0.2
Onobrychis viciaefolia	-	-	0.2	-	0.1	-	0.5	-	1.2	0.3	1.9	1.0
Total legumes[e]	na	na	na	na	14.9	8.3	5.0	2.6	73.3	60.4	45.9	29.5
Forbs:												
Ambrosia psilostachya	nd	nd	nd	nd	nd	nd	nd	nd	0.5	0.2	T	0.1
Salsola kali	21.6	19.9	30.1	25.6	T	-	-	-	T	-	T	-
Undifferentiated	0.2	0.1	0.2	0.1	0.6	0.4	0.1	0.1	0.1	T	T	0.1
Total forbs[e]	na	na	na	na	0.6	0.4	0.1	0.1	0.5	0.2	0.1	0.1
Shrubs:												
Gutierrezia sarothrae	-	-	-	-	0.5	-	-	-	1.1	0.3	-	0.3
Bare ground	75.1	69.9	75.3	67.2	63.5	52.4	40.1	33.5	47.9	30.9	28.9	19.3
Litter	19.9	25.1	19.7	27.8	31.5	42.6	54.9	61.5	47.1	64.1	66.1	75.7

Source: DePuit and Coenenberg (1979)

[a]Light rate = 37 kg/ha avail. N, avail. P @ 41 kg/ha in 1975 and 11 kg/ha in 1976 and 1977, no applied K_2O; all plots fertilized in 1975, 2/3 in 1976 and 1/3 in 1977.

[b]Medium rate = 74 kg/ha avail. N, avail. P @ 41 kg/ha in 1975 and 11kg/ha in 1976 and 1977, no applied K_2O; all plots fertilized in 1975, 2/3 in 1976 and 1/3 in 1977.

[c]Heavy rate = 121 kg/ha avail. N, avail. P @ 41 kg/ha in 1975 and 11 kg/ha in 1976 and 1977, no applied K_2O; all plots fertilized in 1975, 2/3 in 1976 and 1/3 in 1977.

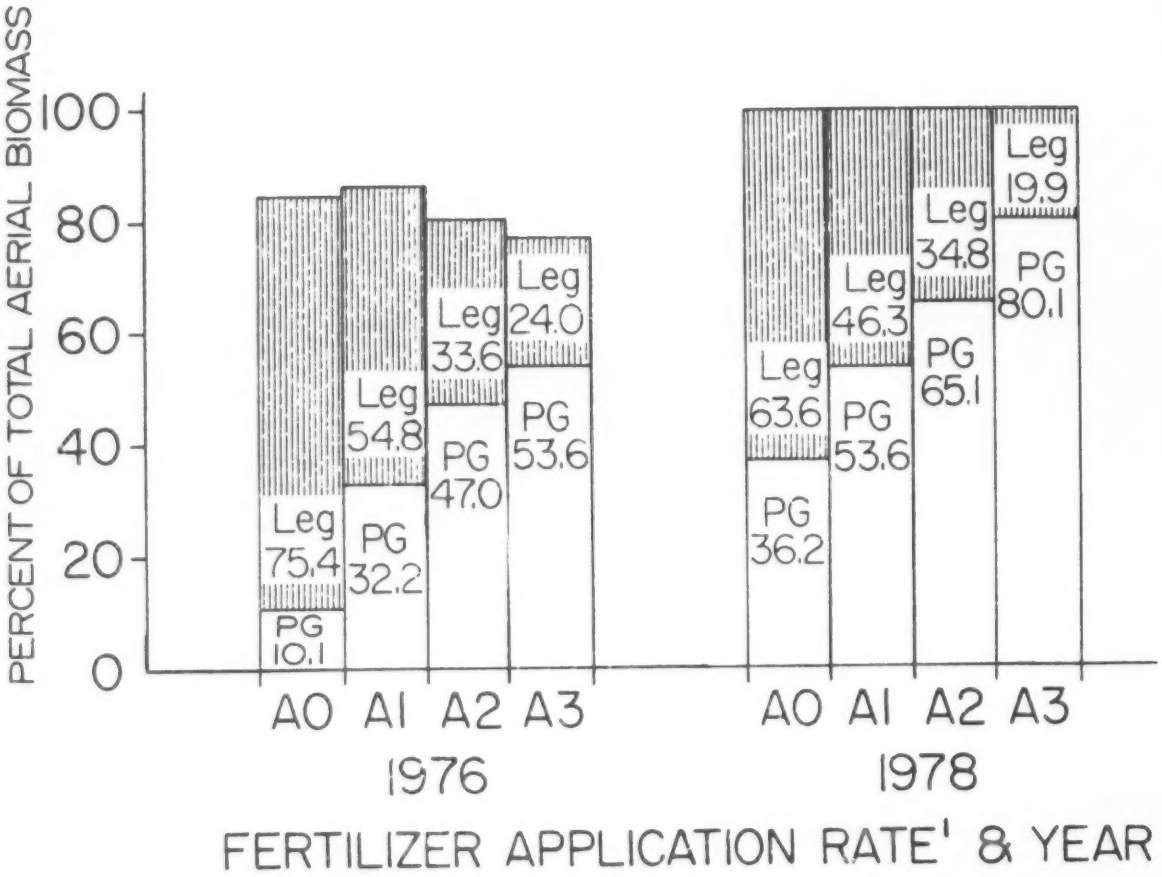
[d]Primarily *Agropyron dasystachyum*.

[e]Not a summed parameter; independently determined.

[f]nd = non-differentiated species during a given year's sampling.

[g]na = not measured during a given year's sampling.

[h]T = trace (<0.1%)



A0 = no fertilization; A1 - light rate; A2 - medium rate; A3 = heavy rate

Figure 36.14. Graphic representation of effects of fertilizer application rate on perennial grass versus legume stand composition, Colstrip, Montana, 1976 and 1978.

Source: DePuit and Coenenberg (1979a:53)

Table 36.60. Overall effects of specific fertilization duration and rate treatment combinations on aerial biomass (kg/ha), fertilizer study, Colstrip, Montana, 1978[a].

Treatment Combination[b]	Perennial Grasses	Treatment Combination[b]	Legumes	Treatment Combination[b]	Total Biomass
F3A3	3624a	F0A0	1712a	F3A3	3832a
F3A2	2734b	F1A1	1599ab	F3A2	3518ab
F2A3	2176c	F1A2	1489ab	F2A1	3165bc
F2A2	1877cd	F2A1	1447ab	F3A1	3111bcd
F3A1	1829cd	F3A1	1273bc	F1A1	3064bcde
F2A1	1718cde	F1A3	1202bc	F1A2	2892cde
F1A3	1519de	F2A2	941cd	F2A2	2818cde
F1A1	1462de	F3A2	784de	F1A3	2724cde
F1A2	1398e	F2A3	404ef	F0A0	2692de
F0A0	975f	F3A3	208f	F2A3	2580e

Source: Adapted from DePuit and Coenenberg (1979)

[a]Biomass values in columns followed by same letter not significantly different at 5% level.

[b]F0 = not fertilized, F1 = fertilized in 1975 only, F2 = fertilized in 1975 and 1976, F3 = fertilized in 1975, 1976 and 1977; A0 = not fertilized, A1 = light application rate, A2 = medium application rate, A3 = heavy application rate

Table 36.61. Efficiency of total applied N from 1975 to 1977 through fertilization duration and rate treatment combinations in promotion of aerial productivity during the first season (1978) after termination of the overall fertilization program, Colstrip, Montana.

Treatment[a]	Total N Applied 1975 to 1977 (kg/ha)	N Use Efficienty (kg/ha biomass per kg/ha applied N) for Perennial Grasses	N Use Efficiency (kg/ha biomass per kg/ha applied N) for Total Stand Biomass
F3A3	363	9.98	10.56
F2A3	242	8.99	10.66
F3A2	222	12.32	15.85
F2A2	148	12.68	19.04
F1A3	121	12.55	22.51
F3A1	111	16.48	28.03
F2A1	74	23.22	42.77
F1A2	74	18.89	39.08
F1A1	37	39.51	82.81

Source: Adapted from DePuit and Coenenberg (1979)

[a]F1 = fertilized in 1975 only, F2 = fertilized in 1975 and 1976, F3 = fertilized in 1975, 1976 and 1977; A1 = light application rate, A2 = medium application rate, A3 = heavy application rate

additions, the efficiency of N use, measured as kg/ha biomass per kg/ha N, decreased for perennial grass production and to a greater extent for total aerial production.

Factor interaction analysis of the fertilizer rate and duration data resulted in recommendations for light or moderate (74 kg/ha) N rates applied once or light N rates applied twice, all three combinations being equally effective in meeting the goal of balanced perennial grass/legume productivity and high overall stand diversity. In view of the noted decline in efficiency of N use with increased total N applied, the light N rate applied once emerges as the best duration/rate combination.

Heavier and/or more frequent N applications would be more advantageous if increased perennial grass productivity, at the expense of legume (and, in some cases, total stand) productivity was desired. It would, though, constitute a less efficient use of applied N. Lighter and/or less frequent N applications would tend to reduce perennial grass and increase legume productivities.

Richardson et al. (1975) and Farmer et al. (1974) studied the effects of fertilization, topsoiling, irrigation, and mulching on the establishment of native and introduced species on coal spoils at the Decker Coal Mine in south-eastern Montana. The three main treatments were: (1) topsoiling (20.3 cm soil), (2) irrigation, and (3) a control (raw spoil). Mulches and fertilizers were imposed on these main treatments.

Seed-bed preparation consisted of ripping all soils to a depth of 25.4 cm, and then harrowing several times with a spring-toothed harrow until the soils were friable and no large clods were present on the surface. A small seed spreader was used to apply a commercial, granular 15-40-5 fertilizer (mixed with silica sand as a carrying agent) at 336 kg/ha. The fertilizer was raked in manually. Mixtures of native, introduced, and native plus introduced species (Table 30.3) were broadcast in the fall at a rate of 28.6 kg/ha and raked lightly. Data on seedling emergence and dry matter production were collected in

October of the first and second growing seasons. The studies are complex and the reader is encouraged to read the reports for details on methods and results.

Emergence was not significantly affected by fertilization on the control plots (Farmer et al. 1974). On the mulched, top-dressed plots, fertilizer decreased emergence from 69 to 62 seedlings per square metre. Fertilizer had no effect on the unmulched plots. No emergence data were taken for the irrigated plots; however, the authors noted a similarity to the control plots.

First season dry matter production showed that fertilizer effects were often modified by the effect of the mulch (Figure 34.2). On the control plots only the introduced grasses growing in mulch produced significantly more dry matter when fertilized. Production on the mulched, top-dressed plots was somewhat higher when fertilized for all grass mixtures. On the unmulched plots fertilization improved growth of the introduced and native plus introduced mixtures.

On the irrigated plots, fertilization significantly increased production for all mixtures. The effect was most pronounced on the mulched plots.

From these first-year results Farmer et al. (1974) concluded that fertilizers improved plant production, especially when combined with mulches. The addition of fertilizer did not, however, improve production as much as expected.

Richardson et al. (1975) have reported on the preliminary second season production results. Fertilization increased production in every case (Figure 34.3), especially in the control and irrigated plots. The authors did not discuss reasons for the difference between first and second season production levels.

On coal spoils in North Dakota, Ries, Sandoval and Power (1977, 1978) set up 9 m x 9 m plots to study the effects of surface soil replacement depths and fertilization on the establishment of Agropyron cristatum or a native grass mix composed of 35% Agropyron smithii, 20% Stipa viridula, 15% A. trachycaulum, and 10% Andropogon scoparius.

Spoil characteristics are described in Chapter 33.3. Grasses were seeded in March at 16.8 kg/ha using a double disc drill with depth bands. One half of each grass plot was fertilized with 56 kg/ha N and 112 kg/ha P, broadcast before seeding. Density and dry matter production were measured in July of the second and fourth growing seasons.

Fertilizer had no effect on Agropyron cristatum plant densities but significantly increased dry matter production (Table 36.62). This increased dry matter production was evident in the second growing season but not in the fourth. Ries, Sandoval and Power noted that the difference in response may have been due to less soil water available for plant growth in the fourth season. Exactly the same trends were seen for the native grass stands (Table 36.62); A. smithii and S. viridula made up 92% of the cover.

The authors stated that topsoil replacement was the most important factor in amending the spoils. Fertilizers appeared to be more important in restoring productivity than in stand establishment at this site. The beneficial effects of fertilization at this site were found to be highly dependent on soil moisture conditions.

Power et al. (1974) and Sandoval et al. (1973) studied the effects of varying N and P rates on growth of Hordeum vulgare, on coal spoils in North Dakota.

In the first experiment, overburden materials present in the upper mantle (above 9.1 m) and the lower mantle (between 12.2 and 24.4 m) were collected and placed in gallon cans in a growth chamber. Hordeum was grown as the test crop and watered to maintain near-optimum moisture conditions. Plants were fertilized with nitrogen (100 ppm), phosphorous (400 ppm), nitrogen and phosphorus or nitrogen, phosphorus and minor elements (1.8 ppm manganese, 10 ppm zinc, 0.16 ppm copper, 5 ppm iron). A set of controls received no fertilizer. Total dry matter production was determined at the heading stage of growth.

The addition of N alone had no effect on Hordeum yields (Table 17.3); however, the addition of P improved growth slightly.

Table 36.62. Effects of fertilizer on establishment and production of crested wheatgrass and a native grass mixture, sown on coal spoils in North Dakota.

	Parameter			
	Density (Plants/m^2)		Production (kg/ha)	
	With Fertilizer	Without Fertilizer	With Fertilizer	Without Fertilizer
Crested wheatgrass	58 a	58 a	2155 b	1022 a
Native grass	54 a	50 a	1015 b	635 a

Source: Adapted from Ries, Sandoval and Power (1978).
Note: Means for the same parameter with different letters and significantly different (5%), according to Duncan's Multiple Range Test.

Fertilization with N and P produced yields three times greater than controls on the upper mantle materials and 15 times greater on the lower mantle materials, indicating a substrate dependent response. There was no significant increase in growth with the addition of micro-nutrients.

In the second experiment, field plots were set out on a newly levelled spoil pile in the spring. The four main treatments and five fertilizer levels are shown in Table 17.4. Plots were seeded to Hordeum vulgare and irrigated throughout the season. Dry matter production was assessed at the heading growth stage.

Hordeum production was improved with the addition of P alone or in combination with N (Table 17.4); however, N alone had no effect. Increasing P from 22.4 to 224 kg/ha also improved yield. The combination of 224 kg/ha of P plus 22.4 t/ha of gypsum produced the best overall yields. The authors noted, however, that even the best yields were only one third (approximately) of pre-mining yields.

Halvorson et al. (1980) studied the effects of three topsoil depths and three fertilizer levels on growth of Triticum aestivum planted into eight coal overburden materials near Underwood, North Dakota. A description of the plot materials has been presented previously (Chapter 33.3). Fertility rates of 0, 33.6, or 67.2 kg/ha nitrogen and 0, 22.4, or 44.8 kg/ha phosphorus, respectively, were added to all plots. The plots were disced and planted to T. aestivum on 18 May.

Yields of straw and grain, taken in the fall, were low due in part to an unusually dry summer and severe sawfly damage. There were no consistent responses to the fertilizer treatments. The greatest response came from increasing topsoil depths.

Bauer, Berg and Gould (1978) and Bauer et al. (1978) studied the effects of various combinations of broadcast N and P and banded P on growth and yield of Triticum aestivum and Zea mais, planted on three coal mine spoils at the Consolidation, Knife River, and Baukol-Noonan sites in North Dakota.

At the Consolidation Coal Company site, spoils were levelled during the fall of 1973 to a 9% slope. In the summer of 1974 the sites

were covered with 0.6 m of stockpiled A and B horizon material. In the spring of 1975, fertilizer P (0-46-0) was broadcast and disced in at rates of 0 and 45 kg/ha. At seeding, 0 and 12 kg/ha P were banded in rows with Triticum aestivum cv. Waldron seed and 0 and 18 kg/ha P were banded 5 cm to the side and 5 cm below the rows of Zea mais cv. High-n-Dry (85 day relative maturity). The banded P was placed at right angles to the broadcast P. Fertilizer N (34-0-0) was broadcast at 0, 22, 45, and 67 kg/ha on the Triticum plots and at 0, 34, 67, and 101 kg/ha on the Zea plots. Triticum was seeded in 18 cm rows at a rate equivalent to 80.6 kg/ha viable seeds. Z. mais plots also received 2.2 kg/ha $Na_2ZnEDTA$.

Yields of Triticum grain and straw were significantly improved with the addition of fertilizer P (Table 36.63), with the greatest improvement coming from the 45 kg/ha broadcast application. There was no significant increase in yield when P was both banded and broadcast over P broadcast alone. The response to fertilizer N was variable.

Zea mais yields were also improved by the addition of fertilizer P (Table 36.64). There were no significant differences in yield between the three levels of P. Response to nitrogen, as with Triticum, was variable; however, the addition of 34 kg/ha N did produce significantly more silage (mean of all P treatments) than the other treatments.

The variability in response to fertilizers was not unexpected, as the pre-seeding soil analysis indicated that the site was low in available P but had adequate levels of N.

At the Knife River site, spoils were levelled to a 1% slope in the fall of 1974. In the spring of 1975, fertilizer P (0-46-0) was broadcast at 0, 34, and 101 kg/ha immediately before the application of four topsoil thicknesses. Fertilizer P was band applied to plots at rates of 0, 11, and 34 kg/ha. Triticum aestivum cv. Waldron and Zea mais cv. High-n-Dry were again seeded at the same rates as at the Consolidation site. Fertilizer N (34-0-0) was uniformly broadcast at 90 kg/ha on Triticum plots and 112 kg/ha on Zea plots. Zea plots also received 2.2 kg/ha $Na_2ZnEDTA$.

Table 36.63. Spring wheat grain and straw yield (kg/ha) at Consolidation Coal Company, North Dakota as affected by fertilizer P rate and placement and fertilizer N rate, 1975.

P broadcast kg/ha	P drill, kg/ha	N rate, (kg/ha) 0	22	45	67	Mean
Grain						
0	0	548	718	813	843	732 a
0	12	880	913	1156	981	981 b
45	0	1108	934	1599	880	1129 c
45	12	1095	941	1747	867	1162 c
	Mean	1042 b	994 b	1055 b	914 a	
Straw						
0	0	1213	1706	1236	1245	1351 a
0	12	1819	1823	1995	1888	1882 b
45	0	2518	2466	2499	2369	2463 c
45	12	2748	2681	2499	2276	2551 c
	Mean	2074 ab	2171 b	2057 ab	1944 a	

Source: Reproduced from Bauer, Berg and Gould (1978), Reclamation of Drastically Disturbed Lands, 1978, pages 451-466 by permission of the American Society of Agronomy, Crop Science Society of America and Soil Science Society of America.

Note: Mean values followed by different letters differ at the 5% level, according to Duncan's Multiple Range Test.

Table 36.64. Corn silage yield (kg/ha, 70% H_2O) at Consolidation Coal Company, North Dakota as affected by fertilizer P rate and placement, and fertilizer N rate, 1975.

P broadcast kg/ha	P drill, kg/ha	N rate, kg/ha 0	34	67	101	Mean
0	0	8 482	10 201	7 351	7 587	8 470 a
0	18	10 437	11 250	9 931	8 246	9 966 b
45	0	9 777	10 531	9 872	11 321	10 378 b
45	18	9 931	11 050	10 119	10 590	10 425 b
Mean		9 660 a	10 755 b	9 318 a	9 506 a	

Source: Reproduced from Bauer, Berg and Gould (1978). Permission as per Table 36.63.

Note: Mean values followed by different letters differ at the 5% level according to Duncan's Multiple Range Test.

Yields of both Triticum and Zea were poor at this site due to both the "dryness" of the topsoil and low rainfall. Increases in topsoil depth increased yields in all cases. No consistent trends were seen with increased application of broadcast P (Table 36.65). Yields of Triticum grain (Table 36.65) and Zea silage increased with the addition of band-applied P but there were no significant differences between the 11 and 34 kg/ha rates. Triticum straw yields also improved with the addition of band-applied P; however, the yields were significantly higher for the 11 kg/ha rate than for the 34 kg/ha rate.

At the Baukol-Noonan site, spoils had been levelled and seeded to a mixture of Medicago sativa, Melilotus sp., Agropyron cristatum, A. intermedium, and Bromus inermis during the spring of 1973. In October 1974, the area was broadcast fertilized with P (0-46-0) and in the spring of 1975 with N (34-0-0). Rates are shown in Table 36.66.

At this site, fertilizer N increased yield of the grass/legume mixture while P had no effect (Table 36.66). Bauer, Berg and Gould noted that the response to N and P was expected since soils tests indicated low available N and a moderate amount of P. They noted that many grasses do not respond to P applications unless there is very little available P in the soil.

From these three studies the authors concluded that yield improvements of Triticum and Zea were predictable, based on N and P soil tests, except where yields were affected by water stress, as at Knife River. The poor response to fertilizer P of the grass/legume mixture was not predicted by the soil tests but was expected for the vegetation type, indicating the importance of species specific responses to fertilization. In addition, response of crops to fertilizers was dependent on topsoil thickness.

Howard, Schuman and Rauzi (1977) studied the effects of nitrogen and phosphorus fertilization on topsoil and overburden from two coal mines and a uranium mine in Wyoming. Topsoil and newly uncovered overburden were randomly collected from the Wyodak Mine near Gillette, the Seminoe No. 1 Mine near Hanna, and the Utah International Uranium Mine near Shirley Basin. The material was ground and thoroughly mixed

Table 36.65. Spring wheat grain and straw yield (kg/ha), and corn silage yield at Knife River, North Dakota as affected by fertilizer P rate.

P drill (kg/ha)	P broadcast (kg/ha) 0	34	101	Mean
Wheat Grain				
0	111[a]	140	165	139 a
11	241	184	171	198 b
34	192	185	191	189 b
Mean[b]	181	170	176	
Wheat Straw				
0	601	675	800	691 a
11	940	932	910	927 c
34	699	841	865	802 b
Mean[b]	747	816	858	

Source: Adapted from Bauer, Berg and Gould (1978). Permission as per Table 36.63.

Note: Values followed by different letters differ at the 5% level according to Duncan's Multiple Range Test.

[a] Values are means of four topsoil thicknesses.

[b] No statistical analyses provided.

Table 36.66. Grass/legume mixture yield (kg/ha) at Baukol-Noonan Coal Company, North Dakota, as affected by fertilizer N and P rate.

N rate, kg/ha	P rate, kg/ha					
	0	6	17	50	151	Mean
34	1244	1236	1335	1208	1530	1310 a
67	1250	1552	1448	1343	1304	1379 a
134	1683	2045	1985	1808	1635	1831 b

Source: Reproduced from Bauer, Berg and Gould (1978). Permission as per Table 36.63.

Note: Means followed by different letters differ at the 5% level according to Duncan's Multiple Range Test.

prior to the greenhouse studies. The pretreatment pH and EC_e of the soils are given in Table 33.35.

The seven treatments imposed on the Wyodak Mine and Seminoe No. 1 Mine soils and overburden are shown in Tables 33.36 and 33.37 Three treatments were used with the Utah International Mine soils (Table 36.67).

Agropyron dasystachyum cv. Critana, Medicago sativa cvs. Ladak and Selection A741 were grown in all treatments. Pots were seeded in February and harvested three times for the grass and five or six times for the Medicago crop. Soil moisture was kept at optimum levels and temperatures ranged from 12°C at night to 35°C by day.

For the Wyodak site materials, the addition of N significantly improved grass growth and yield over the unfertilized soil mixes (Table 33.36). The addition of P significantly improved legume yields only in the mixed topsoil/overburden pots. Sludge improved yields of both grass and legume while manure improved the legume yield only.

For the Seminoe materials, the addition of N significantly improved grass yields over the unfertilized soil mixes (Table 33.37). The addition of P similarly improved legume yields. Both sludge and manure improved grass and legume yields.

The addition of N or P significantly improved grass and legume yields, respectively, at the Utah International Mine (Table 36.67). The addition of sludge improved yields but not to the same extent as the fertilizers.

From these studies Howard, Schuman and Rauzi (1977) noted that forage plants grown on coal spoils benefited from the addition of fertilizers. The addition of sewage sludge or manure improved yields over the controls at both sites.

36.4 OTHER GEOGRAPHIC REGIONS

Boutillier and Morton (1978) tested the effects of two fertilizer rates and two seeding rates (56 and 112 kg/ha) on the growth of seven single species and 14 seed mixes sown on coal spoils at Point Aconi, Nova Scotia.

Table 36.67. Oven-dried forage yields for Utah International Uranium Mine, Wyoming soils and overburden for three treatments using 12 cm pots under greenhouse culture.

Treatments	Forage yield[a] (g)	
	Alfalfa[b]	Grass[c]
1. 5 cm topsoil over overburden	19.1b	4.57c
2. 5 cm topsoil over overburden +		
67 kg N/ha	--	11.10a
67 kg P/ha	28.7a	--
3. 5 cm topsoil over overburden +		
22.4 MT/ha sludge	26.0ab	6.73b

Source: Adapted from Howard, Schuman and Rauzi (1977).

Note: Column yields followed by same letter do not differ at the 5% level of probability by Fisher's method.

[a] Single plot means from four reps.

[b] Sum of six 1975 harvests on 3/18, 4/23, 5/21, 6/26, 6/28, 9/2 of alfalfa (seeded 12/17/24).

[c] Sum of three 1975 harvests on 3/18, 5/21, 9/2 of thickspike wheatgrass (seeded 2/18/74).

The species and mixtures used are shown in Table 23.1 along with height measurements taken at the end of the first growing season for the 56 kg/ha seeding rate. No data were presented for the higher seeding rate. Plant growth was improved under the high fertilizer level for all species and mixes. The authors noted that the higher seeding rate should be used when the low fertilizer rate is employed, in order to maintain an acceptable cover.

Czapowskyj and Sowa (1976) studied the effects of mulching, liming, and fertilization on the survival and growth of Coronilla varia cv. Penngift in Pennsylvania.

The experimental site was on the plateau top of a coal-breaker refuse pile. The refuse, composed of fragmented carbonaceous rocks associated with coal seams but separated from coal in a cleaning plant, has been described, along with planting methods and substrate treatments in Chapter 34.2.

Lime was the most important factor in survival and growth of the C. varia probably because of the ameliorating effect on pH. Fertilizers had no effect on plant survival (Table 34.10). Cover was temporarily improved only with large additions of fertilizer and only in one of the two plantings.

On acid coal spoils near Beckley, West Virginia, Jones, Armiger and Bennett (1975) and Jones, Armiger and Hungate (1973) examined the effects of phosphorus fertilization. In the first study, two mountain sites were selected for evaluation of experimental stair-step terraces on outer slopes. The White Oak Mountain site had an initial pH of 4.1, and the Bolt Mountain site had a pH of 2.9. The slope at each location exceeded 65%.

Experiments were conducted on a split plot design comparing three rates of rock phosphate with superphosphate. Plots were laid perpendicularly to the slope, divided, and randomly seeded to a special legume, either directly or by transplanted greenhouse grown seedlings spaced about 46 cm apart, on the stair-step terraces. Lotus corniculatus cv. Empire was used at White Oak Mountain, and both Lotus and Coronilla varia cv. Penngift were used at Bolt Mountain. Eragrostis

curvula was seeded to provide quick cover and stabilization. Plots were limed, mulched, and fertilized with 56 kg/ha N, 168 kg/ha K_2O, and 1.12 kg/ha molybdenum.

Yield data for two growing seasons were taken in the fall. Response of the legumes to fertilizers varied with species and planting method. Legume yield at the Bolt Mountain site was also dependent on the response of the overseeded E. curvula to fertilizers.

In the second study, spoils had the following characteristics: pH ranging from 3.8 to 4.0; organic matter from 0.2 to 0.3 %; available CaO averaged 216.4 kg/ha; P_2O_5 13.5 kg/ha; and K_2O 83.0 kg/ha. The 0.5 ha field experiment was established with three replicates of 20 different combinations of fertility treatments, including: 0.9, 1.8, and 2.7 t/ha of rock phosphate and dolomitic limestone; 89.7, 179.4, 269.0 and 358.7 kg/ha P_2O_5 from superphosphate; and 1.12 and 2.24 kg/ha of molybdenum. Rock phosphate and superphosphate rates were also compared with a fixed rate of potash at 224.2 kg/ha K_2O. A blanket application of nitrogen was applied at seeding and a maintenance application was broadcast each spring.

Amendments were applied with a 91.4 cm spreader and incorporated into the top 8 to 10 cm of spoil with a spring-tooth harrow for seed-bed preparation. All molybdenum treatments were applied in solution, using a knapsack sprayer. Seeding rates were 33.6 kg/ha for Bromus inermis, 28 kg/ha for Festuca arundinacea cv. Ky 31, 28 kg/ha for Dactylis glomerata and 22.4 kg/ha for Phleum pratense, or about double those normally used on agricultural soils. The entire experimental area was then mulched with straw.

Herbage yield data were determined from two harvests made in each year. Complete ground cover was established for all species in the first season. In most cases, growth or yield differences were not statistically different among the 4.5, 9.0, or 13.5 t/ha rates of rock phosphate or dolomitic limestone. Results, therefore, are presented for means of these treatments. No other statistics were presented by the authors. Three-year average forage yields (dry weight basis) are presented in Figure 36.15 for the four species. Bromus had greatest

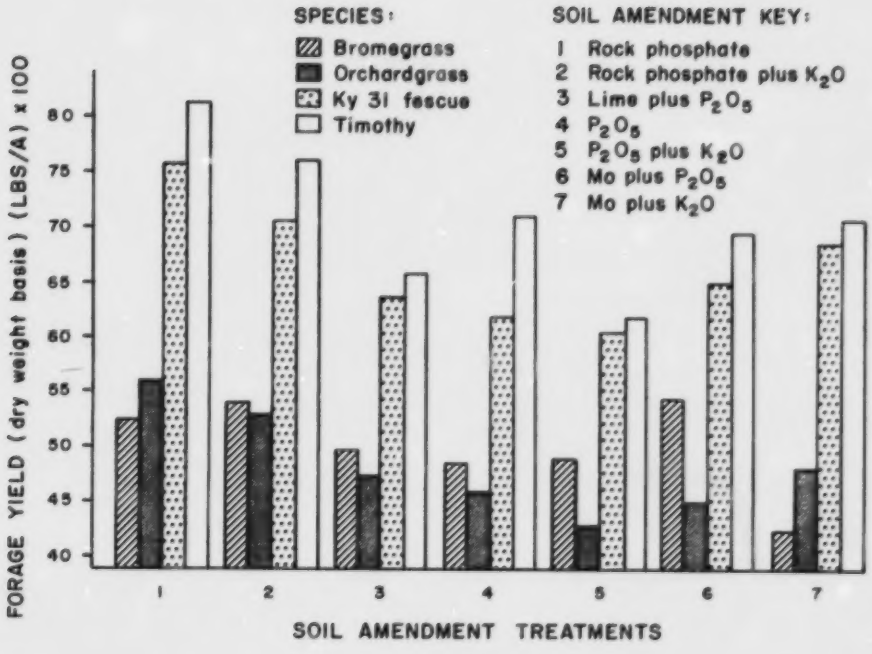


Figure 36.15. Three year average forage yields from various fertilizer treatments, White Oak Mountain, West Virginia.

Source: Jones, Armiger and Bennett (1975a)

yields on the rock phosphate plus K_2O and molybdenum plus P_2O_5 plots, while the other species performed best on plots receiving rock phosphate. It is interesting to note that Festuca and Phleum pratense had greater yields than Bromus or Dactylis. The former, particularily, is well known to respond to fertilization.

From these two studies it appears that grasses responded to the fertilizers more consistently than the legumes. Jones, Armiger and Hungate (1973) concluded that the extra cost of transplanting legumes was not warranted given the success of the seeded plants. Jones, Armiger and Bennett (1975) noted that growth on the plots receiving molybdenum was equivalent to that of plots receiving lime, indicating the potential for replacing large quantities of lime with molybdenum.

Barnhisel, Powell and Akin (1975) have reported on two studies of phosphorus fertilization effects on coal spoils in Kentucky. At the first site near Rosine, Kentucky, the spoils were comprised of gray, weakly cemented shale and siltstone having a neutral pH and containing little or no sulfide minerals (very low potential acidity). Chemical tests indicated that these spoils were very low in plant-available phosphorus and nitrogen but contained adequate amounts of potassium, calcium, and magnesium. Site preparation methods were discussed in an earlier section (Chapter 34.4). Phosphorus (superphosphate 0-46-0) rates are shown in Table 34.30. Nitrogen, as prilled ammonium nitrate, was applied at a rate of 28 kg/ha at seeding, in the fall of 1972 and in the spring of both 1973 and 1974. The seeding rate for Festuca arundinacaea cv. Ky 31 and Trifolium pratense was 44.8 and 13.4 kg/ha, respectively.

Plots were harvested for three years and oven-dried forage yields calculated. A uniform plant population of both species was established on all plots. During the summer and fall, however, plants on plots not receiving phosphorus developed severe phosphorus deficiencies and stands progressively decreased until some areas were bare. Melilotus officinalis seed was apparently present as only this species occurred on the plots with no phosphorus in the second season.

Phosphorous applications increased forage yield on all plots in 1973 (Table 34.30). However, the magnitude of the yield increase became smaller in succeeding seasons and virtually disappeared by 1975. Barnhisel, Powell and Akin (1975) noted that plant available P had declined in all plots over the three growing seasons. It is interesting to note the steady increase in yield with time on plots not receiving P and the steady decrease on plots with higher P applications.

From this study Barnhisel, Powell and Akin noted that first season forage yield response to phosphorus fertilization was encouraging; however, further applications would probably be required to maintain adequate yields.

At the second site, spoils orphaned for seven years were smooth graded for a study on the effects of lime and phosphorus on yield of Festuca and Trifolium. A randomized split-plot experimental design with four replications was utilized by arranging plots 5 x 10 m for the three lime and four phosphorus treatments. Phosphorus was applied as concentrated superphosphate (0-46-0) and as rock phosphate (colloidal). The added materials were incorporated to a depth of about 8 cm with an agricultural tractor-mounted chisel plow. Ammonium nitrate (33.3% N) was added at a rate of 34 kg/ha and the plots were seeded to F. arundinacea cv. Ky 31 at 40 kg/ha and to T. pratense cv. Kenstar at 17 kg/ha. In July 1973 symptoms resembling potassium deficiency were noted and 67 kg/ha as 0-0-60 was applied. This failed to correct the problem, and it was surmised that the problem was insufficient nitrogen. This was alleviated by the application of 17 kg/ha as ammonium nitrate. Additional nitrogen was applied in 1974 (34 kg/ha) and in 1975 (17 kg/ha). The area was not harvested in 1973. The first harvest was in June 1974, and subsequent harvests in August 1974 and June 1975.

Yields were improved by the increasing levels of superphosphate (Table 36.68) in all three harvests; however, yield improvement was probably significant only at the first harvest. The rock phosphate treatment resulted in yields between the 0 and 85 kg/ha superphosphate treatments. As in the first experiment Barnhisel,

Table 36.68. Mean[a] oven-dried forage yields (kg/ha) as affected by phosphorus treatments on orphan spoils near Rosine, Kentucky.

Harvest Date	Phosphorus Treatment			
	0	85 kg/ha	170 kg/ha	3.4 t rock phosphate
6 74	695	1013	1464	874
8 74	299	336	383	301
6 75	1159	1176	1385	1237

Source: Barnhisel, Powell and Akin (1975).
[a] Averages from four replications and across all lime treatments.

Powell and Akin (1975) noted that refertilization would be required to maintain high yields.

Fitter and Bradshaw (1974a,b) examined the effects of fertilizers on growth of Lolium perenne cv. S.23 and Agrostis tenuis growing on acid colliery spoils in South Lancashire, England.
In the first experiment, a split-plot factorial experiment of two levels of N, P, K, and lime was used in the field or in the greenhouse. Five sites were chosen for study. In the field experiments, small plots were set out and all possible combinations of N, P, and K at 5 or 50 kg/ha were tested along with limestone at 0 or 12.5 t/ha. In the greenhouse experiments, pots were filled with spoils from the five mine sites and all possible combinations of N, P, and K at 2.5 and 25 kg/ha were tested along with lime at 0 or 12.5 t/ha.

Field plots were planted to Lolium and Agrostis in April and harvested in September. Pots were sown to Lolium in June and harvested nine weeks later. One field plot was destroyed and another heavily grazed.

Differences in response to N, P, and K were most pronounced in the greenhouse. Lime had a more pronounced effect on the more acid spoils (Tables 36.69). On three of the spoils tested, growth was limited without the addition of the high P level though growth was significantly improved by P on all spoils (Table 36.69). Nitrogen significantly improved yields in three spoils in the greenhouse but only one spoil in the field. Potassium had no effect in the field. In the greenhouse, yields in two shales were reduced when K was added.

In the second experiment, Lolium perenne cv. S.23 was sown at three sites. Lime and fertilizer rates are shown in Table 36.70. Root penetration was measured in September as total length per gram of shale, at three depths. Data from two of the sites, with similar pH, were combined as there were no statistical differences in response to fertilization.

Fertilizer improved surface root growth (Table 36.70), and plant biomass, (Table 36.71) especially on the less acid site. Only the highest fertilizer rates produced root growth at the 100 cm depth.

Table 36.69. Mean yields (g/m^2) in factorial experiments on acid coal spoils in England.

	Site: Grammar		Outwood		Maypole Limestone		Low Hall		Duke's Pit	
	+	-	+	-	+	-	+	-	+	-
Glasshouse: Lolium										
1 npk	15.8	2.1	5.9	0.3	39.4	31.3	2.0	1.0	20.5	22.7
2 npK	7.9	0.9	8.6	0.3	42.3	53.6	2.3	0.5	17.5	19.3
3 nPk	36.8	6.3	42.1	1.1	30.0	49.3	35.6	0.6	24.7	29.6
5 nPK	30.0	2.4	43.6	0.5	47.6	79.8	33.3	0.7	28.7	32.2
5 Npk	11.3	3.9	16.4	0.8	65.3	29.4	2.2	3.2	37.3	37.1
6 NpK	4.3	4.0	9.6	0.5	55.4	93.4	1.8	1.2	32.8	73.4
7 NPk	54.5	32.5	82.4	0.8	141.0	218.0	21.3	5.4	38.3	114.8
8 NPK	29.1	9.0	34.2	0.9	104.1	174.7	27.3	6.2	43.9	105.5
9 Nil	5.8	1.4	15.4	0.2	51.7	41.4	1.3	0.8	22.6	18.8
Field: Lolium										
1 npk	3.4	0.1	10.0	0.0	23.8	16.6	4.6	0.0		
2 npK	4.2	0.0	12.2	0.0	15.0	7.0	1.4	0.0		
3 nPk	7.2	0.9	13.4	0.3	35.4	17.2	15.0	0.0		
4 nPK	5.0	0.5	14.8	0.0	39.4	15.8	10.2	0.0		
5 Npk	5.0	0.5	10.6	0.0	47.2	18.0	4.6	1.0		
6 NpK	3.6	0.1	6.4	1.1	39.4	19.8	7.4	0.0		
7 NPk	5.2	0.8	18.2	1.6	42.4	21.4	18.6	0.0		
8 NPK	14.2	3.3	21.2	1.3	38.2	21.2	16.8	0.0		
9 Nil	0.6	0.6	8.2	0.0	22.2	7.6	1.8	0.0		
Field: Agrostis										
1 npk	1.0	0.1	1.2	3.7	5.2	3.8	5.4	0.1		
2 npK	0.8	1.5	1.2	1.3	1.4	5.0	3.4	0.1		
3 nPk	7.6	2.1	2.2	0.4	3.8	2.8	8.2	0.1		
5 nPK	0.8	2.6	4.8	0.0	7.4	5.0	3.8	0.0		
5 Npk	0.6	0.0	2.4	0.2	9.2	4.0	3.4	0.0		
6 NpK	2.4	0.3	0.8	1.8	12.2	12.2	4.0	0.0		
7 NPk	5.0	1.2	1.2	0.0	9.4	12.6	11.6	0.0		
8 NPK	3.2	1.8	1.2	0.7	9.6	20.8	10.6	1.3		
9 Nil	1.6	1.0	0.8	0.6	2.8	3.0	1.2	2.3		

Source: Fitter and Bradshaw (1974a)

Note: Values for Grammar field plots are grazed and hence not comparable.
N P K represent 25 or 50 kg/ha; n p k 2.5 or 5.

Table 36.70. Root development of Lolium perenne on acid coal spoils in England (mm/g shale).

Lime (t/ha)	Fertilizer [a] (kg/ha)	Depth in soil (mm) 0 to 20	40 to 60	100 to 120
Acid sites. Outwood and Low Hall, pH 3.1 to 3.3				
0	0	0.03 a	0.00 a	0.00 a
	125	0.60 a	0.33 a	0.00 a
	625	0.43 a	0.00 a	0.00 a
2.5	0	65.70 a	0.07 a	0.00 a
	125	214.30 bc	2.80 a	0.00 a
	625	421.37 d	90.83 b	3.97 b
12.5	0	102.77 ab	0.93 a	0.00 a
	125	279.03 c	25.03 ab	1.10 a
	625	484.77 d	3.53 a	1.63 b
Maypole, pH 4.7				
0	0	15.30 a	0.00 a	0.00 a
	125	362.30 ab	47.05 bc	21.45 ab
	625	484.55 bc	98.05 de	20.50 ab
2.5	0	240.45 ab	3.00 a	0.00 a
	125	525.85 bc	17.35 ab	3.10 a
	625	987.60 d	101.10 e	41.10 b
12.5	0	10.35 a	0.30 a	0.00 a
	125	72.75 a	16.80 ab	0.00 a
	625	794.80 cd	59.95 cd	17.50 a

Source: Fitter and Bradshaw (1974b).

[a] Fertilizer (17-17-17).

Note: Within columns for one site, figures postscripted by different letters differ significantly by Duncan's new multiple range test, with P equal to 0.05.

Table 36.71. Plant yields from three acid coal spoils in England (g/m^2).

Limestone (t/ha)	Fertilizer (kg/ha)	Outwood	Low Hall	Maypole
0	0	0.00a	0.00a	2.20a
0	125	0.24a	1.16a	6.96a
0	625	0.00a	0.00a	50.12b
2.5	0	2.12ab	1.04a	4.88a
2.5	125	9.92b	8.44b	5.92a
2.5	625	19.40c	15.48c	39.96b
12.5	0	1.16a	2.44a	7.88a
12.5	125	8.80b	7.20b	10.64a
12.5	625	21.08c	22.40c	41.72b

Source: Fitter and Bradshaw (1974b).

Note: Within columns, different subscripts indicate a significant difference by Duncan's new multiple range test, with $P = 0.01$.

Yield was improved by fertilization at the acid sites only when they were limed.

From this study Fitter and Bradshaw noted that response to fertilizers was linear up to the highest rate and liming was effective only on the very acidic site. Fertilizers also improved root growth, demonstrating their importance in providing seedlings some protection from drought.

Gemmell (1975a) studied the effects of fertilizers on establishment and growth of Festuca rubra and Trifolium repens sown on weathered blast furnace slag waste heaps in Britain. In the first experiment, a mixture of Festuca (95%) and Trifolium (5%) was sown at a rate of 100 kg/ha. The clover was inoculated with the appropriate Rhizobium species before sowing. Fertilizer N, P_2O_5, and K_2O were each applied at 0, 50, and 100 kg/ha as ammonium nitrate, calcium monophosphate, and potassium sulphate. Response to the fertilizers was assessed through a visual growth index since visual acceptability in this area was regarded as more important than yield production.

Analysis of variance showed significant main effects, attributable to nitrogen and phosphate in combination but not to potash or nitrogen alone. Nitrogen applied at 50 kg/ha (average of all combinations with P) caused a significant growth response to occur but 100 kg/ha was not significantly better than the control. Both phosphate levels increased growth, 100 kg/ha being significantly better than 50 kg/ha. The appearance of phosphate deficiency symptoms at the time of assessment and the failure of Trifolium to develop beyond the early seedling stage indicated that phosphate was the principal growth limiting factor in the waste. The immobilization of applied phosphate was attributed to the formation of insoluble calcium phosphates as a result of the high pH (9.0) of the waste.

The second experiment was designed as a split-plot involving four large blocks, two of which were seeded to F. rubra at 100 kg/ha and the other two to F. rubra at the same rate plus 5% T. repens. Each block was split into five plots, receiving the following nitrogen regimes in June 1972: no N, 50, or 100 kg/ha N as urea (N), and 50 or

100 kg/ha N as sulphur-coated urea (SN). Every plot was treated with phosphate and potash at 75 kg/ha P_2O_5 and K_2O, respectively.

The maintenance treatments commenced in early September 1972. Each split-plot was subdivided into three subplots, two of which were treated with 100 kg/ha N as either urea or sulphur-coated urea, the third plot being a control. Each subplot was further subdivided into half subplots, one receiving a top-dressing of phosphate at 125 kg/ha P_2O_5 and the other being a control. Finally, in mid-May 1973, all the swards were treated with 125 kg/ha of N, P_2O_5, and K_2O so as to assess the residual effects of the establishment treatments.

Variance analysis of the visual growth response data for October 1972 revealed significant effects of the initial N treatments and the maintenance N and P treatments (Tables 36.72 and 36.73). The initial application of slow-release N provided better growth than did the soluble N. There was a significant interaction between the maintenance N and maintenance P applications. The addition of slow-release N and maintenance P provided the best growth response.

Gemmell (1975a,b) noted that the large response to maintenance phosphate, and the absence of nitrogen effects when extra phosphate was not supplied, were good evidence that phosphate was the principal growth limiting factor in the waste, as was earlier suggested. Further, the superiority of slow-release nitrogen over soluble nitrogen, emphasized the leaching problems associated with the addition of this nutrient to the waste.

The rapid immobilization of the initially applied phosphate was almost certainly the cause of the failure of *T. repens* to establish. Although germination did occur, the seedlings perished, exhibiting symptoms of severe phosphate deficiency.

At the second assessment in May 1973, the pattern of treatment effects was similar to the initial assessment (Table 36.73) but the effects of the maintenance N and its interaction with maintenance P were much greater. The combination of slow-release N and an application of P again produced the best growth (Table 36.74).

Table 36.72. Growth responses of Festuca rubra and Trifolium repens to nitrogen and phosphate assessed at five months from initial treatment and two months from maintenance fertilization, plots on weathered blast furnace slag in England.

Means visual growth indices (1 to 5)					
Initial nitrogen treatments					
	Nil N	N1	N2	SN1	SN2
	1.67a	2.03b	226bc	2.40c	2.49c
Maintenance nitrogen treatments					
		Nil N	N	SN	
		1.76a	2.23ab	2.52b	
Maintenance phosphate treatment					
			Nil P	P	
			1.55a	2.79b	
Interaction: maintenance nitrogen x maintenance phosphate					
Nil N	N	SN	Nil N	N	SN
P_0	P_0	P_0	P_1	P_1	P_1
1.43a	1.58a	1.65a	2.09b	2.89c	3.39d

Source: Adapted from Gemmell (1975a).

Note: The means were compated by Duncan's New Multiple Range Test. Any two values followed by the same letter are not significantly different at $P = 0.05$.

Table 36.73. 'F' values obtained in analyses of variance of visual growth assessment results from NPK experiment on after-management, England.

Source of variation	October 1972	May 1973	July 1973
Total whole plots:			
Blocks	7.9*	18.1#	14.4#
N_1 (initial N)	10.3	19.4#	6.9*
Total sub-plots			
N_M (maintenance N)	5.4*	97.0#	12.4#
$N_1 \times N_M$	0.8	1.1	2.8
Total sub-plots			
P (maintenance P)	193.4#	204.6#	262.1#
$N_1 \times P$	1.8	0.8	0.6
$N_M \times P$	12.4#	54.9#	11.0#
$N_1 \times N_M \times P$	1.0	1.0	0.8

Source: Adapted from Gemmell (1975a).

* Significant at the 1% level.

\# Significant at the 0.1% level.

Table 36.74. Assessment in May 1973 of maintenance nitrogen and phosphate applications, on weathered blast furnace slag in England.

Mean visual growth indices (1 to 10)		
Nil N	N	SN
P_0	P_0	P_0
1.47a	2.68b	3.03b
Nil N	N	SN
P_1	P_1	P_1
1.53a	4.93b	6.52c

Source: Adapted from Gemmell (1975a).

Note: The means were compared by Duncan's New Multiple Range Test. Any two values followed by the same letter are not significantly different at $P = 0.05$.

By the second assessment, the residual effects of the initial N application showed that the slow-release urea at 100 kg/ha produced better stands than all other treatments. Gemmell found intact sulphur-coated urea present on the plots at this time, indicating that nitrogen was still being released, thus enhancing growth.

Following the blanket application of N, P, and K in mid-May, a final assessment was made in mid-July. The pattern of response was again similar (Table 36.73) though the effects of the N treatments were reduced. Phosphate was still the most important growth factor.

Gemmell noted that there were no differences in effect of initial N application type or level by the third assessment, indicating no long-term benefit from slow-release N fertilizers. There was, however, a significant effect from the use of slow-release N when applied as a maintenance fertilizer. In addition, the use of a slow-release N maintenance fertilizer, in combination with P, produced the best growth on all plots.

From these studies Gemmell (1975a,b) recommended an initial leaching period (15 to 24 months) to reduce spoil pH, in effect reducing the chance of fertilizer P being immobilized. This is especially important when legumes are being established, as shown by the failure of legumes in this trial. The use of slow-release N improved growth on the porous, free-draining spoils in this study. Gemmell also recommended using slow-release N as a maintenance or second fertilizer application as it would have more effect than when used as an initial treatment.

Michelutti (1974) has reported on a study of the effects of five fertilizer types on growth of plants on nickle mine tailings from the Sudbury, Ontario region. The five fertilizers tested were: (1) 10-10-10; (2) 6-9-6 (50% urea formaldehyde); (3) 12-4-8 (66% urea formaldehyde); (4) 15-5-10 (40% urea formaldehyde); and (5) 2-1-2 (sheep manure). Rates of application were equivalent to 0, 0.6, 1.1, 1.7, 2.2, 4.5 and 6.7 t/ha. Yield data were collected for a 10-week growth period in a greenhouse. No statistical analyses were performed.

Best growth was obtained with the slow-release 6-9-6 fertilizer at 1.7 t/ha. Growth from this treatment was much better than from the 10-10-10 at 1.1 t/ha which was the standard operational reclamation level at that time. Michelutti (1974) also noted the reduced yields at the higher fertilizer levels and attributed this to osmotic pressures created by the addition of fertilizer salts.

Hodgson and Townsend (1973) discussed the effects of two forms of nitrogen and four forms of phosphate on growth of Brassica hirta, sown onto lagooned, pulverized fuel ash (PFA) in greenhouse trials. Nitrogen was applied as ammonium and nitrate at 0.8 g/21.6 cm pot and phosphate was applied as P_2O_5 at 0, 1.87, and 3.74 g/pot. All pots received a basal application of K. At the first cropping, the nitrate fertilizer produced somewhat better growth than the ammonium, especially when phosphate was also added. By the second cropping, however, there was little or no difference between fertilizer types. Hodgson and Townsend suggested that the ammonium source may be less efficient due to: (1) the absence of nitrifying bacteria in freshly deposited PFA, and/or (2) loss of the ammonium in gaseous form when the fertilizer is spread on the alkaline PFA.

In the phosphate experiment, B. hirta was grown in pots receiving 0.89 g N and a basal application of K along with one of four phosphate sources at 1.87 or 3.74 g/pot P_2O_5. Phosphate sources were orthophosphoric acid, mono-calcium phosphate, di-calcium phosphate, and calcium meta-phosphate. The water soluble forms of phosphate produced more growth than the insoluble forms. Doubling the applied phosphate increased yield only with the calcium meta-phosphate fertilizer.

Hodgson and Townsend have also reported on a field trial designed to assess the effectiveness of eight soil amendments and two fertilizer levels on a crop rotation of Brassica sp. and Lolium perenne sown on pulverized fuel ash in England. The high rate of fertilization was four times the low rate. Yield data were collected in the second to fifth seasons. In all cases, yields were higher with the higher fertilizer rate. The effect of the fertilizers was least where sewage

sludge was used to amend the ash, indicating sewage was already acting as a source of nutrients.

Handley et al. (1978) reported on an experiment conducted by Chestnutt and Lowe in 1970 which demonstrated the importance of the interaction between liming rates (acidity) and fertilizer types on grass/legume yields. In order to select optimum conditions for clover growth a mixed sward, containing grasses and three clovers (Trifolium pratense, T. repens and T. hybridum), was sown at four lime levels with five phosphate sources. Productivity was strongly influenced by lime/phosphate interaction as shown in Figure 36.16. Superphosphate, an acidic fertilizer, gave poor results without lime and at the lower lime rate of 1000 kg/ha. Seedling establishment may have been inhibited by phosphate toxicity under these conditions. Basic slag, in contrast, was satisfactory in the absence of lime but phosphate availability declined as the lime rate increased. The effect was very marked with rock phosphate and bone meal which could provide a long term supply of phosphate, as dissolution rate increases due to natural acidification. Magnesium ammonium phosphate (Enmag), an expensive material with slow release properties, gave satisfactory results at all lime levels, with an optimum at 2500 kg/ha.

In another study Bradshaw et al. (1975) found that a modest fertilizer treatment (NPK at 60, 26, and 49 kg/ha, respectively), applied with seed by a hydroseeder, produced a 60% inhibition of Trifolium repens establishment under greenhouse conditions. A further experiment showed reduced germination by Lolium perenne and T. repens when exposed to fertilizers, especially nitrogen. Experiments in solution culture demonstrated the susceptibility of Trifolium seedlings to toxicity of NH_4^+ and $H_2PO_4^-$ during the establishment phase. They felt that the dominant influence would be the ammonium ion and noted that Trifolium mortality could be reduced by the use of a protective peat mulch (to reduce evaporation and concentration of these ions) together with an appropriate slow-release nitrogen fertilizer.

Johnson, Bradshaw and Handley (1976) examined the ability of commercial and metal-tolerant varieties of Festuca rubra to establish

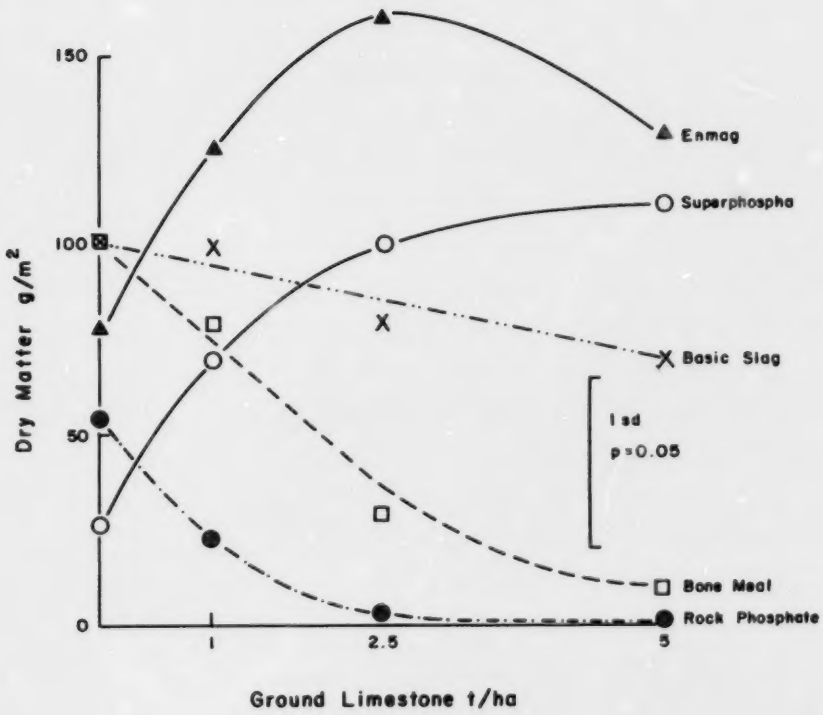


Figure 36.16. Mean herbage yield of a grass/clover mixture 16 months after establishment on China clay sand waste with five phosphate sources at four lime levels.

Source: Handley et al. (1973)

and grow on metal-contaminated fluorspar (CaF_2) tailings and metalliferous mine wastes in the U.K. Properties of the tailings from four fluorspar mines and two lead-zinc mines are listed in Table 36.75.

Festuca rubra was sown at a rate equivalent to 50 kg/ha in pots in a greenhouse. Half of the pots were amended with a compound inorganic fertilizer at a rate equivalent to 75 kg/ha of N, P_2O_5, and K_2O.

The addition of fertilizer significantly improved growth of both the commercial and metal-tolerant varieties on the low-zinc fluorspar tailings but significantly improved the growth only of the metal-tolerant variety on the other wastes.

Following these studies, the authors set up a field trial to test the effects of fertilizers on six grass and legume species and three mixes grown on the No. 1 and 2 dams (Table 36.75). Plots were set out in April and amended as follows:

1. Sewage sludge; 20 t/ha.
2. Farmyard manure; 20 t/ha.
3. Inorganic NPK; 50 kg/ha N, P_2O_5, K_2O.
4. NPK + superphosphate P; 50 kg/ha N, P_2O_5, K_2O + 100 kg/ha P_2O_5.
5. Untreated.

The organic amendments were incorporated into the top 10 cm of tailings while the inorganic fertilizers and seed were lightly raked into the surface layers. The plots were harvested seven months after sowing and data on dry matter production were taken.

The addition of fertilizers improved growth of almost all species. The added input of superphosphate further improved plant growth. Johnson, Bradshaw and Handley noted that while growth in the fertilized plots was satisfactory, the stands gradually regressed due to leaching of essential nutrients. Sewage sludge proved to be the best amendment in this study.

Table 36.75. Chemical composition of four fluorspar and two lead-zinc mine tailings in the U.K.

Mine	Concentration (ug/g oven-dried tailings)			
	Pb	Zn	N	P
Glebe dam	38 000	18 500	25	12
Cupola dam	34 000	3 050	230	597
No. 1 and 2 dam	11 000	2 020	33	80
No. 3 dam	9 400	1 460	41	49
Trelogan	40 000	95 000		
Mill Close	6 000	46 000		

Source: Adapted from Johnson, Bradshaw and Handley (1976).

36.5 SUMMARY

Evaluation of fertilizer effects in the Oil Sands region has been made quite complex by the large number of fertilizer trials combined with numerous soils mixes. As a general prescription, application of 90 kg/ha N, 23 kg/ha P, and 90 kg/ha K with extra N-S application in August is supported by several years of research. However, this treatment is definitely not optimal for all vegetation and soil conditions.

The low level of fertilization prescribed is sufficient to establish adequate cover. Late fertilization provides early and rapid growth in the following year, which is critical where erosion may be a factor. Higher fertilizer rates will definitely increase production and may be optimum depending upon species and end land use; in the Oil Sands area there does not appear to be a need for such rates.

High fertilizer rates favour Bromus inermis while low rates or no fertilization favour Festuca. On plots receiving intermediate rates of fertilizer, Bromus gradually replaces Festuca. Bromus provides high biomass production but also results in high moisture loss. Festuca, on the other hand, produces low biomass and also creates rodent problems. Legume production decreases as fertilizer rate increases.

Micronutrients and lime do not appear to provide major or consistent vegetation improvement on oil sands materials.

Studies carried out on china clay wastes and other sandy textured tailings would seem to be relevant to the Oil Sands. Research has indicated that nitrogen is the main limiting nutrient. Stands can be established without difficulty but deteriorate rapidly without maintenance fertilizer. Ammonium nitrogen provides better results than nitrate nitrogen in sandy soils because of the susceptibility of these soils to rapid leaching.

Legumes are depressed by high nitrogen levels, and encouraged by high phosphorus levels which provides a better grass-legume mix. This is important as legumes are essential for continued nitrogen supply, which may be depleted by extensive leaching.

Considerable research is required in order to prescribe optimum fertilizer rates for the various grass and legume species, soil materials and mixes, and soil forming processes in the Oil Sands.

Research at high elevations (mountains and foothills) and in arctic sites has indicated considerable variation in response to fertilization according to species, site, and soil. An overall best fertilizer selection would be very difficult based on available information.

Fertilization is required in the first year for optimum establishment of grasses and legumes. Fertilization is not required every year but a one-year application is insufficient, particularly for agronomic species. On arctic sites, even the most vigorous species show a decline after four to five years; the length of time for maintenance fertilization is still unanswered. To date, the procedure for maintenance fertilization seems to be to fertilize in year one and then refertilize according to visual stand condition. Most agronomic species and species mixes will respond to refertilization but the response varies tremendously with species.

High rates of fertilizer do not always produce best results. Native species do not usually respond well to high rates. Several studies have indicated best results with low rates of fertilizer (as little as 60-30-60 kg/ha N-P-K has been suggested). Where moisture is limiting, high fertilizer rates may not produce increased vegetation production, and if they do, root systems will probably not support the added production. In general, high rates may provide quick cover but are of little value over the long-term.

There is a definite change in fertilizer response with elevation. Above treeline response is very limited. In the subalpine zone, fertilizers increase establishment and production while at lower elevations response is again reduced. As well, need for maintenance fertilization appears to decrease with decreasing elevation. Studies have indicated this trend for both grasses and legumes.

Other site treatments affect the response to fertilizer. Considerable variation in response has been seen between raw spoil and

top-dressed plots. A number of studies have indicated that top-dressing greatly reduces the need for more than minimum rates of fertilization.

Studies indicate that phosphorus is the most important element to be supplied in high elevation and arctic sites. Nitrogen may be beneficial but generally results in best response when supplied in combination with phosphorus. Phosphorus may be rendered unavailable on high or low pH spoils so that recommended rates vary greatly; as much as 800 to 1600 kg/ha has been recommended on some highly calcareous sites.

Fertilization favours grasses over legumes, although legumes respond very well to phosphorous fertilization.

Van Cleve (1977:432) was referring specifically to boreal and arctic regions when he noted that, "fertilization has a marked favourable impact on the rate, amount, and longevity of cover production. In most cases growth of introduced species without fertilization has shown limited success or no success two to three years after seedling establishment. Extent of depletion of nutrient capital during disturbance coupled with generally low available contents of important nutrients in these cold-dominated soils necessitates the use of fertilizer...." However, these remarks are valid for high elevation sites as well. Considerable research is needed to determine optimum fertilizer prescriptions for individual species under various site treatments.

In plains regions fertilizer trials have been carried out on raw spoils that were apparently of relatively good quality till, as well as on top-dressed plots.

Commercial crops such as barley, wheat, oats, and corn respond well to fertilizers. In Alberta 71 kg/ha N produced barley yields slightly above regional mean yields. Alfalfa rotation seems to reduce reliance on fertilizer and barley variety may be important. These plots were amended with 15 cm of good quality soil.

In Montana 90-121-45 kg/ha of $N(NO_3)$ - $P(P_2O_5)$ and $K(K_2O)$ provided the best yield of spring and winter wheat and barley on raw spoil. Further testing of phosphorous at < 180 kg/ha (P_2O_5) was considered necessary. Oats responded best under low (45-56-22 kg/ha

N-P-K) fertilizer. However, even highest grain yields were low compared to yield on unmined areas. Low yields of barley, wheat, and corn were similarly experienced in North Dakota. In North Dakota there was no response of barley to N alone, while P or N-P combination increased yields.

Response of grasses and legumes on raw spoils is very similar to other geographic regions. Increasing fertilizer rates depress establishment of legumes and annual grasses and favour perennials such as Agropyron cristatum and Bromus spp.. Salsola kali competition increases with high rates of fertilization but tends to disappear by the third year. Annual fertilization and high rates provide high biomass but decrease stand diversity and legume content and one-year fertilization is recommended if diversity is an objective. Low rates of fertilizer (e.g., 24-32 kg/ha of actual N-P) are generally recommended, particularly if fertilization is carried out on an annual basis. Efficiency of nitrogen use (kg biomass per kg N) is greatest with low applications. Stand composition can be varied quite well by manipulating number of applications and rate of fertilizer.

When used in combination with other amendments (topsoil, mulch, irrigation) the relative effect of fertilizers is often quite low. Best results have been obtained in combination with mulches. Topsoil provides much greater benefit than fertilizer.

Timing of fertilizer application is important. Application shortly before seeding may provide better response (establishment) than application after seeding. Soil moisture is of course important to achieving maximum results. Slow release nitrogen fertilizers are highly recommended for porous, free-draining spoils, and for maintenance fertilization.

One study indicated that wheat and corn yields could be predicted from spoil tests for N and P.

Studies in other regions (e.g., eastern United States, Britain) have tended to support observations reported above and have indicated that special measures are required on problem spoils.

Phosphorus deficiency is a problem on high and low pH wastes. Phosphorus can be immobilized on these sites and initial high rates and maintenance fertilization are generally required. On high pH spoils, leaching before fertilization is often recommended. On low pH spoil, liming is usually required; molybdenum was noted as a substitute for lime in one study. Liming rate x fertilizer type interactions can be very important, particularly with respect to phosphorus. Superphosphate is acidic and requires increased lime application. Rock phosphate and bone meal provide long term supplies of phosphorus on basic spoils due to natural acidification. Magnesium ammonium phosphate gives satisfactory results over a wide range of liming rates.

In general, amendments in addition to fertilizer are required for optimum performance (establishment and yield) of cereal crops, and fertilizer requirements can generally be predicted from spoil and soil nutrient levels. In contrast, more research is required on optimum rates and maintenance fertilizer requirements of various species and species mixes of grasses and legumes, particularly in mountain, foothills, and northern regions. Fertilization could be a critical cultural tool for stand manipulation.

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SECTION XI

ESTABLISHMENT OF TREES AND SHRUBS IN RECLAMATION

37. ESTABLISHMENT OF TREES AND SHRUBS BY SEEDING

37.1 SPOT SEEDING

Selner and Thompson (1977) examined the effects of soaking seed for 24 hours in water, at room temperature, on germination of Pinus banksiana, Picea glauca, Pinus contorta var. latifolia, Abies lasiocarpa, Picea mariana, Larix laricina, Pinus albicaulis, and Pseudotsuga menziesii in peat amended tailings sands in Alberta. For each species, 100 seeds (soaked or unsoaked) were evenly spaced along a shallow trench 5 mm deep and 1 m long. Only P. menziesii (12%), Pinus contorta var. latifolia (8%), and Pinus banksiana (26%) seeds germinated and had significant numbers of seedlings survive by the end of the first growing season. Soaking the seeds did not appear to increase the chance of germination or survival.

Selner, King and Hildebrandt (1977) tested 10 tree and shrub species on coal spoils at Tent Mountain, Alberta. Species and seeding rates are shown in Table 37.1. Untreated seed was sown in separate, 10 m long, 3 mm deep furrows. Seed was evenly applied along the row and covered with a layer of soil equal to the thickness of the seed. The trial area was fertilized with 11.2 kg N, 14.6 kg P, 9.0 kg K, and 4.5 kg S per hectare.

By the end of the first growing season, only four species had germinated none with a rate greater than 0.005%: (1) Picea engelmannii, (2) P. glauca, (3) Pinus contorta var. latifolia, and (4) Pseudotsuga menziesii. The authors observed rodents digging up and eating Pinus albicaulis and Pseudotsuga menziesii seeds.

Mihajlovich and Russell (1980) examined these plots in the second and third growing seasons and found that seedling establishment was poorer than in the first year.

On coal spoils near Middlesboro, Kentucky, Wittwer, Graves and Carpenter (1979) seeded Pinus virginiana, Quercus rubra, Q. prinus, and Q. palustris with or without mulch and fertilizer. For Quercus rubra and Q. palustris, two acorns were placed in each hole. Pinus virginiana was planted at six to ten seeds per spot. For Q. prinus, a species

exhibiting no winter dormancy, a single acorn with a normally developing radicle was placed in each hole.

All species established well in the first year (Table 39.17) with Quercus rubra and Pinus virginiana doing best with fertilizer and mulch. The authors concluded that Quercus and P. virginiana can be established by direct seeding techniques, especially when spoils are fertilized and mulched. They noted that this was important because bare-root Quercus seedlings often fail due to difficulties with the prominent taproot system.

37.2 BROADCASTING

Finn (1958) found that direct seeding of trees on ungraded strip mine banks was generally a failure. The reasons for failure were many, but on strip mined land it was often due to seed being washed away or covered by erosion. Schessler and Bergoffen (1964) found that woody plant seeds had low germination levels and were often eaten by rodents, thus reducing the success of direct seeding trials.

Sheldon (1975), in a discussion on the reclamation of slate wastes in Wales, noted that large seeded species such as Quercus and Platanus occidentalis had a much greater probability of becoming established than did smaller seeded species such as Betula and Salix. The smaller seeded species were better adapted to moist soils.

Selner and Thompson (1977) broadcast seeds of Alnus crispa, Betula papyrifera, Alnus tenuifolia, and Rosa woodsii onto peat amended tailings sand in Alberta. After broadcasting, the seed was raked in and the soil was compacted for improved moisture retention. No germination was observed at the end of the first growing season.

At Tent Mountain, Alberta, Selner, King and Hildebrandt (1977) broadcast seeded 10 tree and shrub species during the spring onto a coal spoil dump. Species and seeding rates are shown in Table 37.1. At the time of seeding, Rhizobium inoculated Medicago sativa cv. Roamer and Melilotus officinalis were broadcast at 9.1 kg/ha and 13.6 kg/ha, respectively. The trial area was then fertilized with 28 kg N, 36 kg P,

Table 37.1. Species and seeding rates used in Tent Mountain, Alberta trials.

Genus and Species	Common name	Row Seeding Trial Seed Application Rates		Broadcast Seeding Trial Seed Application Rates	
		g/m	Average Number seeds/m	kg/ha	Average Number seeds/m
Alnus crispa	Green alder	1.4	4 000	0.1	80 000
Alnus tenuifolia	Mountain alder	1.4	2 100	7.8	4 725 000
Betula papyrifera	White birch	1.4	2 410	3.4	4 140 000
Picea engelmannii	Englemann spruce	1.4	422	0.1	6 750
Picea glauca	White spruce	1.4	588	0.2	41 250
Pinus albicaulis	Whitebark pine	21.0	9	0.6	1 500
Pseudotsuga menziesii	Douglas fir	4.2	415	0.8	2 000
Rosa woodsii	Common rose	7.0	781	5.0	225 000
Abies lasiocarpa	Alpine fir	4.2	326	NS	NS
Pinus contorta	Lodgepole pine	1.4	290	NS	NS
Pinus banksiana	Jack pine	NS[a]	NS	0.1	8 200
Picea mariana	Black spruce	NS	NS	0.1	7 800
				18.2	9 237 500

Source: Adapted from Selner, King and Hildebrandt (1977).

[a] NS = Not sown in this trial.

22 kg K, and 11.2 kg S per hectare. A peat mulch was applied at 2.8 m^3/ha, by hand, to ensure complete ground coverage.

The authors found no germination by the end of the first growing season. They attribute the lack of germination to consumption of seed by rodents and birds, lack of seed pretreatment, and poor site characteristics. Mihajlovich and Russell (1980) re-examined these plots in the second and third growing seasons and still observed no germination.

Gallup (1974) reported on attempts to seed native trees and shrubs in the Angeles National Forest. After several years of broadcast seeding, a few plants began to emerge. It was felt that given enough seed and time, seeds would be scarified or stratified by natural means and would germinate.

Draves and Berg (1979) seeded a mix of shrub species, including Rosa spp., Prunus pensylvanica, Amelanchier alnifolia, and Symphoricarpos oreophilus, onto alpine coal spoils in Colorado with and without grasses and forbs. Establishment of the shrubs was highly variable; however, the authors noted that establishment was much lower in areas seeded with grasses and forbs than in areas seeded to shrubs alone. Volunteer establishment by Artemisia tridentata was also suppressed by the presence of grasses and forbs.

DePuit and Coenenberg (1979) broadcast seeded and cultipacked a mixture of grass, legume, and shrub species onto coal spoils in Montana at a rate of 33 kg/ha. Grass and legume establishment was very good but shrub establishment was very poor. On the other hand, Sindelar et al. (1974) seeded 16 shrub species, four of which had attained densities several times those found in mature shrub communities after one growing season. On unamended, sloping scoria fill, DePuit and Dollhopf (1978) found that 11 out of 14 species seeded in five mixes were established by the end of the fourth growing season.

Aldon (1975) has had some success in seeding Atriplex canescens onto coal spoils in New Mexico. Jensen and Sindelar (1979) found that A. canescens was the only reliable shrub species out of 11

tested on roadside sites in Montana. Sarcobatus vermiculatus was somewhat successful if seeded in the fall.

Bengtson, Mays and Allen (1973) seeded Pinus taeda at 1.4 kg/ha on acid coal spoils in north-eastern Alabama, with or without fertilizer and a grass cover crop. Establishment was best for the fertilized plots with no grass cover. First winter mortality was highest on unfertilized plots.

Zarger et al. (1973) and Bengtson, Mays and Zarger (1971) seeded P. taeda onto similar spoils in Alabama under three fertilizer regimes. The higher rates of fertilizer produced better plants though all control plants lived. They also fertilized plots previously seeded to P. taeda and P. virginiana. Fertilization improved vigour and colour but not growth. The authors concluded that fertilizers were mandatory to allow direct seeded plants to develop adequate root systems.

37.3 HYDROSEEDING

Lesko, Etter and Dillon (1975) hydroseeded five seed mixes of grasses, legumes, shrubs, and trees onto coal spoils at the Luscar Mine, near Hinton, Alberta. Establishment rates were extremely low for trees and shrubs. They concluded that hydroseeding of trees and shrubs should be avoided.

Lesko (1974a,b), in hydroseeding studies on sand dunes near Lesser Slave Lake and oil sand tailings at Fort McMurray, Alberta also concluded that hydroseeding was not a suitable method for establishing trees and shrubs on unamended, sandy soils.

Richardson and Dicker (1972) found that two tree species (Fraxinus and Betula) became established when seeded with a light grass cover on coal spoil heaps in England. Acer and Alnus were eliminated by the end of the third growing season.

37.4 SUMMARY

Seeding of trees and shrubs has met with little success in mine reclamation. No information was found on drill seeding and the small amount on spot seeding was variable. Broadcast seeding has been

generally unsuccessful due to factors such as erosion, washing away of seeds, rodent and bird predation, and vegetative competition from grass and forbs. Some success has been obtained with larger seeded species. Hydroseeding of trees and shrubs has met with very little success.

The general forestry literature could probably shed considerable light on this subject area. Information from that source might very well increase the success of seeding operations.

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38. ESTABLISHMENT OF TREES AND SHRUBS BY PLANTING

38.1 CONTAINER STOCK

Containerized stock has certain advantages over bare-root stock which make it useful in the reclamation of drastically disturbed sites. The roots of the container grown seedlings are shaped by the container and remain in a three dimensional arrangement, whereas bare-root seedlings usually end up in a two dimensional plane. Containerized seedlings seldom require root pruning and are minimally disturbed by lifting, packing, transportation, and planting. This means that most of the fine roots and root hairs are not damaged or lost through handling or planting and since they do not lose contact with the soil they are not subjected to excessive drying. In addition, this rooting medium provides the seedlings with an immediately available supply of moisture and nutrients as an aid to early survival and growth (Goodman, Koppe and Hutnik 1977; Balmer 1976). Another advantage is that the undisturbed root systems are often mycorrhizal at the time of outplanting (Baker 1978). Finally, container stock can be grown more quickly than bare-root stock, and can be grown for all planting seasons (USDA, Forest Service 1979).

The uniform size and shape of the root system in the containers also lends itself to using specially designed hand planting tools that minimize stooping during planting. Some systems for planting containerized stock can reduce hand planting time by 50 percent or more (Baker 1978; Balmer 1976).

Jensen and Hodder (1979b) and Hodder (1970) tested several container types in an effort to select a method for revegetating arid roadside sites in Montana. Generally they found that tube materials which were sufficiently strong to remain intact in the continuously damp environment of the greenhouse during the several months required for root development were slow to disintegrate in the field following planting. The need to remove resistant tubes, reusable tubes, and split metal or plastic tubes would add complications to a mechanized planting process. A tube of fine plastic mesh did not effectively contain the

potting soil nor inhibit horizontal penetration of roots into adjoining tubes. These tubes proved to be unmanageable, very difficult, and slow to fill. The most satisfactory potting tube material was a thin absorbent paper tube reinforced with a 1.3 cm mesh plastic sleeve.

One disadvantage of the containerized stock is the higher cost of production (Schiechtl 1980; Balmer 1976). In addition, container stock is quite heavy, which presents shipping and handling difficulties and may increase cost (USDA, Forest Service 1979).

Container stock is difficult to maintain from the time it is delivered until field planting is completed. Proper storage areas, watering facilities, and daily care are needed (USDA, Forest Service 1979). Hodder (1970), however, reported no difficulty in transporting tubed plants over 402 km of arid land in Montana. Care must be taken, however, to provide protection from the wind.

In areas subject to frost, seedlings should have enough time to put down strong anchoring roots before the cold weather sets in, otherwise the transplants may be frost heaved, container and all (Bengtson, Mays and Zarger 1971).

Packer and Aldon (1978) and McKell (1978), in reviewing the literature, have noted that comparisons of plantings of bare-root stock and stock in containers indicate that survival of the containerized plants greatly exceeds that of the bare-root plants in most instances.

38.1.1 Mountains and Foothills Region

Macyk (1972, 1973, 1974a,b, 1975, 1976, 1977a,b, 1978a,b, 1979a,b) and Macyk and Steward (1977) have reported on reclamation efforts from 1972 to 1979 at McIntyre Mines in Grande Cache, Alberta. The No. 8 Mine site was located in the upper Foothills at an elevation of 1615 m. The rooting zone was composed of unconsolidated and weathered mineral material spread over the mining surface. The pH ranged from 7.0 to 7.9, available N was about 0.7 kg/ha, available P ranged from 3.4 to 14.6 kg/ha, and available K was approximately 140 kg/ha (Macyk 1972). Plots were set up on a variety of slopes and a number of experiments were run. *Pinus contorta* var. *latifolia*, *Picea glauca*, and *P. englemanii* were planted as container and bare-root stock.

In June, 1972 one hundred 3+0 bare-root lodgepole pine and 500 one-year-old containerized Pinus contorta var. latifolia seedlings were planted. The seedlings were grown in polyethylene tubes filled with peat. Seedlings were planted with the plastic skin intact, perforated, or removed.

Survival at the end of the first growing season was 25% for bare-root and up to 54% for container stock (Macyk 1974b). Most of the mortality in the containerized stock, in the first growing season, was due to frost heaving (Macyk 1973, 1974b). By the end of the fourth growing season, the containerized shrubs had attained a height of 35 cm while the bare-root stock was only 24 cm tall (Macyk 1976).

The effects of the three container treatments varied according to site (Table 38.1). In Area I the "skin on" seedlings had better survival than the "skin off" seedlings while the reverse was true for Area II (Macyk 1973). Macyk felt that this was probably related to the characteristics of the soil at the two sites (Area I had more organic matter). He noted that the presence of a plastic skin appears to increase the possibility of a seedling being frost-heaved out of the soil as the organic matter content of the soil decreases. An overall assessment of seedling survival indicated that the "skin off" procedure was the most successful of the three treatments employed.

Macyk (1976) discussed the effects of container size on field survival of P. contorta var. latifolia and Picea englemanni. He presented no data but indicated that survival rates for trees grown in larger containers (84 cm^3 or 164 cm^3) were better than those in smaller containers (39 cm^3). In 1977, 7 to 10 month old Pinus contorta and Picea englemanni seedlings grown in Hillson (164 cm^3) and Tinus (492 cm^3) containers were planted (Macyk 1977a). Again both species performed better in larger containers than in the smaller Ferdinands (39 cm^3) or Fives (84 cm^3) containers used in previous years. Survival rate in the Tinus containers, after the second growing season, was 70% (Macyk 1978a).

Leiser et al. (1974) compared establishment and survival rates for Penstemon newberryi and Ceanothus prostratus grown in various container sizes and planted on a granite rock cut in an alpine area in California.

Table 38.1. Percent survival after two growing seasons for lodgepole pine seedlings planted in "peat sausage" containers, Grande Cache, Alberta.

Treatment	Area I % survival	Area II % survival
skin off	60	47
skin perforated	50	28
skin on	74	17

Source: Adapted from Macyk (1973).

Table 38.2 Percent survival of plants in two container sizes in two alpine sites in California.

Species	Container size	Site I % survival	Site II % survival
Penstemon newberryi	gallon	80	92
	paper pot	50	90
	tube	30	83
Ceanothus prostratus	gallon	40	75
	paper pot	10	0

Source: Adapted from Leiser et al. (1974).

The containers used were: (1) 5 cm peat pots; (2) 2.5 cm x 15 cm tar paper tubes; and (3) a crimped, 3.8 L #10 can. Survival was highest for both species in the can (Table 38.2), and slightly better in the peat pots than in the tubes for P. newberryi.

38.1.2 Plains Region

Jensen and Hodder (1979b) made several comparison plantings of tubed plants and conventional bare-root nursery stock in Montana. The first study, at the Pinehills Interchange, examined the success of container versus bare-root plantings. The second study, at the Colstrip Interchange, examined container versus bare-root planting using two moisture conservation methods. The third study, at Pompey's Pillar, tested container versus bare-root plantings, container size, and container propagation methods. Complete details on soils and climate for these study areas are available in the report.

The Pinehills study area was a south facing 1.5:1 slope of sandy gravel material covered with approximately 15 cm of topsoil. Tubeling containers were 6.4 cm in diameter, 61 cm long, made of two-ply absorbent paper, and surrounded by a polyethylene mesh for support. Tubelings and bare-root stock were of the same age, lot, and nursery source. Species tested are shown in Table 38.3.

Due to the presence of Convolvulus arvensis on the study area, Jensen and Hodder (1979b) placed 6 mil thick, black polyethylene tarps on all plots to control weeds. A gas powered soil auger with a 6.4 cm diameter drill was used to drill planting holes through the tarps. In May 1971, tubelings and bare-root stock were dropped into the holes, a shovel used to compress the soil around the roots, and the plots fertilized. The tarps were covered by a layer of coarse gravel to reduce the scalding effect of the black plastic. Plant survival and height data were collected over a six-year period. Data on root development were taken for three species at the end of the third growing season.

With the exception of Fraxinus pennsylvanica and Sheperdia canadensis, the tubelings had higher survival rates by the end of the first growing season (Table 38.3). S. canadensis and Elaeagnus

Table 38.3. Plant survival (%) and average plant heights (cm) recorded at the Pinehills Interchange study area for one year old tree, shrub and vine species planted as greenhouse propagated dryland tubelings and as bare root stock. Planting was completed during May 1971 and data were collected six times during the following five year period.

	September 1971		October 1972		June 1973			
	Tubelings	Bare root	Tubelings	Bare root	Tubelings		Bare root	
	%	%	%	%	%	cm	%	cm
Hanson hedgerose	86.7a[a]	46.7b	80.0a	66.3b	92.2a	68.7x	60.4b	88.8y
Chokecherry	93.3a	73.3b	90.2a	72.1b	82.9a	73.3x	49.0b	70.8x
Green Ash	90.0a	93.3a	94.2a	92.2a	94.6a	98.9x	92.8a	169.2y
Creeping juniper	63.3a	36.7b	51.5a	31.4b	49.6a	46.0x	32.0b	31.3x
Honeysuckle	93.3a	63.3b	93.3a	70.6b	93.3a	120.8x	70.6b	127.2x
Sea buckthorn	63.3a	27.6b	58.3a	27.2b	62.3a	101.3x	27.5b	82.9y
Native plum	100.0a	94.1b	100.0a	90.1b	100.0a	62.3x	89.0b	76.4x
	84.3	62.1	81.1	64.3	82.1	81.6	60.2	92.4
Silverberry	25.0a	8.0b	12.5a	0b	0	0	0	0
Buffaloberry	12.5a	10.2a	0	0	0	0	0	0
Western white clematis	93.3a	80.0b	73.3a	66.7b	72.0a	ND	65.3b	0
Canadian clematis	53.3a	33.3b	33.3a	16.7b	17.0a	ND	6.1b	0
Skunkbush sumac	ND	98.6	ND	97.1	ND	ND	92.0	88.6
Sandcherry	ND	98.1	ND	98.6	ND	ND	98.6	118.3
Caragana	ND	89.1	ND	87.1	ND	ND	88.0	141.4

	September 1973				September 1974				September 1975			
	Tubelings		Bare root		Tubelings		Bare root		Tubelings		Bare root	
	%	cm	%	cm	%	cm	%	cm	%	cm	%	cm
Hanson hedgerose	96.7a	77.4x	60.4b	105.9y	90.0a	79.1x	64.8b	92.2y	90.0a	80.2x	72.5b	93.9y
Chokecherry	79.5a	88.6x	46.8b	74.1x	83.8a	93.6x	46.8b	87.3x	83.8a	101.5x	45.3b	99.8x
Green Ash	94.6a	102.6x	92.3a	170.2y	94.6a	152.0x	92.3a	210.2y	87.2a	175.5x	89.3a	280.6y
Creeping juniper	48.2a	57.8x	36.3b	48.0y	48.2a	58.0x	36.3b	51.0x	48.2a	59.5x	35.4b	86.2y
Honeysuckle	93.3a	121.4x	65.4b	136.3x	86.7a	137.0x	62.5b	148.2x	86.7a	157.4x	62.5b	159.5x
Sea buckthorn	56.3a	121.4x	25.3b	99.8y	58.8a	139.2x	36.2b	122.4y	58.8a	159.8x	37.2b	143.0y
Native plum	100.0a	69.8x	85.8b	84.9y	98.0a	76.2x	85.8b	98.9y	98.0a	89.1x	85.8b	106.3y
	81.2	91.3	58.9	102.7	80.0	105.0	60.7	115.7	78.9	117.1	61.1	138.5
Silverberry	0	0	0	0	0	0	0	0	0	0	0	0
Buffaloberry	0	0	0	0	0	0	0	0	0	0	0	0
Western white clematis	72.0a	ND	63.0b	ND	65.7a	ND	55.1a	ND	60.2a	ND	50.7a	ND
Canadian clematis	17.0a	ND	5.3b	ND	ND	ND	ND	ND	ND	ND	ND	ND
Skunkbush sumac	ND	ND	92.0	94.8	ND	ND	92.0	98.9	ND	ND	92.0	109.9
Sandcherry	ND	ND	98.6	125.1	ND	ND	98.6	137.1	ND	ND	90.3	138.7
Caragana	ND	ND	80.0	146.0	ND	ND	80.0	173.0	ND	ND	80.0	189.0

Source: Jensen and Hodder (1979b:23)

[a] Individual species treatment means within sampling date columns followed by different letters (a and b) or (x and y) within data groups, are different from each other at the 0.05 level (Newman-Keul test). Analyses compares percent survival and rate of growth between tubeling and non-tubeling plants within sampling date.

commutata had extremely high mortality rates the first and second years and had all died by June of the third year. While individual species survival rates varied over the next five years, the tubeling-planted species maintained higher survival rates. In general, the bare-root stock had higher growth rates than did the tubeling stock (Table 38.3). However the growth rates of the individual species varied, depending on planting method. Fraxinus pennsylvanica, Rosa hansoni, and a native Prunus sp. grew best when planted as bare-root stock, while Prunus virginiana, Juniperus horizontalis, and Lonicera sp. growth rates were not affected by planting methods. Hippophoae rhamnoides grew better as tubeling stock.

The roots of Rosa hansoni, Lonicera, and F. pennsylvanica were examined at the end of the third growing season. R. hansoni showed no differences in root growth between the two planting methods. Lonicera roots in the tubeling stock had extensive root constriction and enlarged sections of callous tissue caused by the polyethylene sheath on the tubeling. Fraxinus, which survived poorly as tubeling stock, had severely constricted root systems as a result of the polyethylene sheath.

The second study at the Colstrip Interchange evaluated the success of Caragana arborescens and H. rhamnoides, planted as bare-root and tubeling stock, under two different moisture conserving techniques. The study area was on a south-facing 6:1 slope near Forsyth, Montana. Subsoil was an alkaline sandy loam with a low water holding capacity. Ten centimetres of an alkaline, loamy sandy topsoil, low in nitrogen, was placed over the subsoil. A chisel plow was used to relieve compaction in the upper 20 cm of soil.

Planting was completed during the first week of June, 1972. Condensation trap treatments were constructed by first excavating a hole such as that shown in Figure 38.1. After the plant was placed in position, a 1.3 m diameter, 6 mil thick, black polyethylene sheet with a cross slit in the middle was placed over the plant stem and the edges of the sheet heeled into the soil. The polyethylene and bark chip mulch treatment was installed by excavating a bowl shaped depression, planting

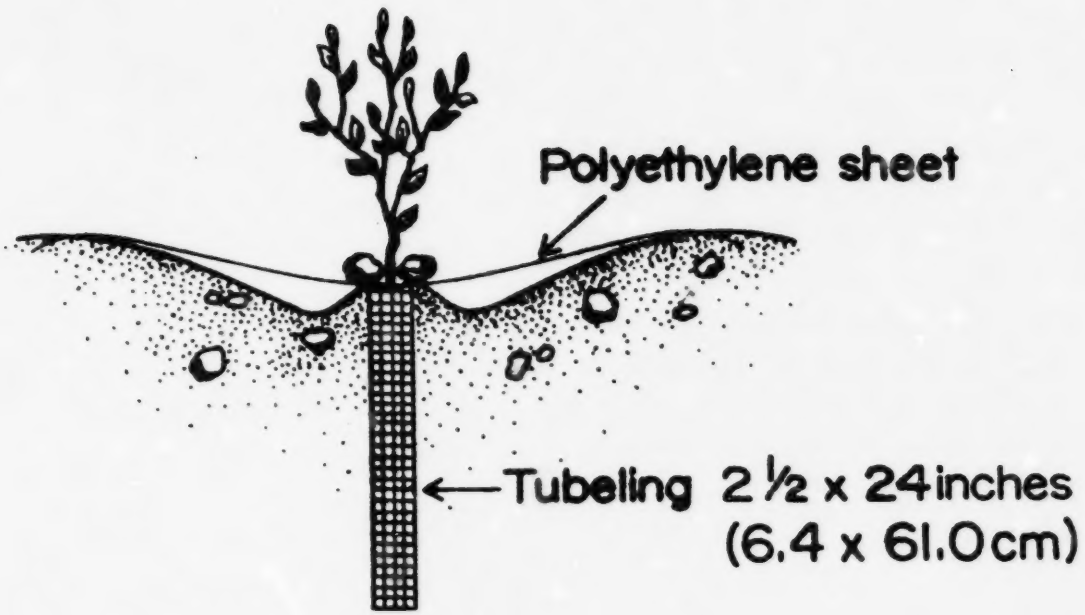

Figure 38.1. A cross sectional view of the tubeling stock and condensation trap method of planting.
Source: Jensen and Hodder (1979b).

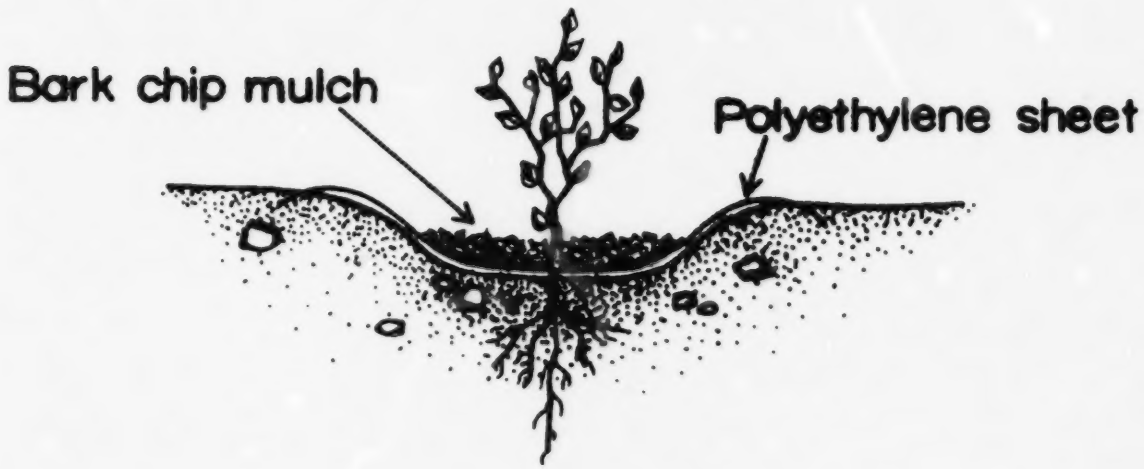

Figure 38.2. A cross sectional view of the bare-root stock and polyethylene covered depression with bark chip mulch method of planting.
Source: Jensen and Hodder (1979b).

a shrub in its centre, placing a 0.9 m square polyethylene sheet over the plant so it lined the depression, and then placing bark chip mulch over the polyethylene liner (Figure 38.2). Each plant was fertilized with a slow release fertilizer tablet (Agriform) placed in the bottom of the hole.

Survival and growth measurements commenced during late July 1972 and were repeated every September through to 1975.

Due to the hardy nature of Caragana, the tubeling method did not prove to be significantly superior to the bare-root method until the second growing season (Table 38.4). From then on the tubeling planted stock survived at a significantly higher rate although planting technique had no effect on growth rates. Root excavations at the end of the second growing season showed that roots from tubeling stock Caragana were fewer and much smaller than those from the bare-root stock.

Hippophoae rhamnoides, on the other hand, established twice as many plants in the first year when planted as tubeling stock than when planted as bare-root stock. Survival of H. rhamnoides was much lower than that of Caragana throughout the study period.

The third study was composed of three sub-studies which examined the effects of: (1) bare-root versus container plantings; (2) two different container sizes (61 cm and 30.5 cm); and (3) two tubeling cultural methods (greenhouse and outside grown tubelings) and two planting methods (tubeling versus bare-root). The study site was located near Pompey's Pillar, Montana on undisturbed native soil, between a highway cut slope and right of way fence. Soil was a 10 to 15 cm layer of sandy loam topsoil covering a sandy gravel subsoil with numerous large rocks.

During May and June 1974, the site was chisel plowed twice in diagonal directions to relieve soil compaction and eliminate vegetative growth.

All plant material, consisting of two-year-old bare-root stock, was obtained during early March. Tubeling stock was started in the greenhouse in 6.4 by 61.0 cm tubelings, assembled, planted, and grown as previously described. Bare-root plant stock required for the planting

Table 38.4. Percent plant survival and average plant height (cm) recorded at the Colstrip Interchange, Montana, study area for two species, tubed and not tubed. Shrubs were planted 1 to 6 June 1972.

	Caragana		Sea buckthorn	
Sampling Date	Survival (%)[a]	Growth (cm)	Survival (%)	Growth (cm)
September 1972				
Tubelings	94.6a	ND	78.4a	ND
Bare-root	89.5a	ND	37.4b	ND
June 1972				
Tubelings	94.6a	53.6a	64.5a	51.2a
Bare-root	89.7a	48.4a	32.0b	49.9a
September 1973				
Tubelings	82.5a	59.8a	42.9a	66.2a
Bare-root	68.0b	60.4a	21.4b	56.4b
September 1975				
Tubelings	79.6a	81.7a	38.5a	95.8a
Bare-root	64.5b	82.4a	21.4b	72.0b

Source: Adapted from Jensen and Hodder (1979b).

[a] Values are means for 2 mulching treatments.

Note: Tubeling and bare-root stock means by species followed by different letters (a-b) are significantly different from each other at the 0.05 level (Newman-Keul Test).

methods comparison was maintained in cold storage until planted. Holes for all bare-root stock were 30.5 cm in diameter, 45.7 cm deep, and dug with a tractor powered post hole auger. Each bare-root plant was hand planted by holding it in the proper position, back-filling, and compacting the soil by foot.

Planting holes for the tubeling stock were excavated with a trailer mounted soil sampling auger 6.4 cm in diameter and 0.9 m in length. The tubeling stock was planted by first cutting the polyethylene mesh tube lengthwise and then sliding the soil and plant root mass into the hole while holding onto the polyethylene mesh tube, thus planting the tubeling without the plastic mesh sleeve. After the tubeling plant was in place a long bladed transplanting spade was inserted into the soil around the hole and moved back and forth to compact the soil against the tubeling root mass.

Plant establishment and growth data collected at the study area during the summer and fall of 1974 did not show the large treatment differences previously recorded at other eastern Montana study areas. The reduced differences between treatments were probably due in part to the greater than normal amounts of precipitation received during May and June 1974. Treatment differences may also have been reduced because critical soil moisture stress, just beginning to develop during late July, was quickly relieved during the abnormally rainy months of August, September, and October. The planting techniques being tested were developed primarily for use under conditions of high moisture stress and high temperatures, but were never exposed to the expected harsh climatic conditions which would have allowed proper evaluation. Another factor which may have influenced establishment and growth rates was the undisturbed native soil profile in which the plants were planted. All other studies were completed on disturbed soil.

Seven species were used to test the effects of bare-root versus container stock (Table 38.5). Statistical comparisons showed container stock of Symphoricarpos oreophilus, Cowania mexicana, and Purshia tridentata had better survival than bare-root stock after the first year. After three years container grown S. oreophilus was no longer superior.

Table 38.5. Study III at the Pompey's Pillar, Montana study area. First and third year survival (%) and height (cm) data for two planting methods and seven species. Species Planted during late May 1974.

Species	61 cm x 16 cm Tubeling				Bare-root Stock			
	Sept. 1974		Sept. 1976		Sept. 1974		Sept. 1976	
	%	cm	%	cm	%	cm	%	cm
Mountain snowberry	98xa	27.6	54b	37.5	83y	21.9	48c	36.3
Stansbury cliffrose	58xc	14.4	31xc	31.7	19yd	18.2	5yd	37.5
Antelope bitterbush	75xb	17.8	52x	38.3	44yc	21.0	20y	39.9
Siberian salt tree	92a	44.8	86a	101.2	96a	55.9	96a	119.7
Peach tree	12d	15.0	6d	59.2	12d	12.3	7d	65.9
Squaw apple	92a	34.4	81ya	80.5	100a	64.3	98xa	107.3
Oldman wormwood	92a	33.1	76ya	69.1	100a	39.4	88xb	72.1

Source: Adapted from Jensen and Hodder (1979b)

Note: Comparable treatment means within rows for the two planting methods followed by different letters (x and y) are significantly different from each other at the 0.05 level (Newman-Keul Test). Treatment means within columns followed by different letters (a to d) are also significantly different. Plant heights were not statistically analyzed.

Third-year data showed that Peraphyllum ramosissimum and Artemisia abrotanum established significantly more plants when planted as bare-root stock. The Prunus fasciculata established poorly, regardless of planting method. Plant growth rates varied widely between species but showed little difference between planting methods. Field inspection in 1978 showed that Halimodendron halodendron was growing well and that S. oreophilus and P. tridentata still had a high survival rate. Artemisia abrotanum, Prunus fasciculata, and Peraphyllum ramosissimum all had unacceptable survival rates.

Three species were used to assess the effect of two tubeling lengths (Table 38.6). The 61 cm tube did not consistently improve survival as compared to the 30 cm tubes; there were no differences by the third growing season. These data must be considered with caution because, as previously stated, the initial establishment period was unusually moist, and moist conditions would tend to negate the benefits derived from the dryland planting technique.

The effects of two cultural methods and two planting methods (Table 38.7) were assessed using six species, all of which responded differently. Juniperus scopulorum, Pinus ponderosa, and Fraxinus pennsylvanica survived at a higher rate when grown as tubeling stock outside of the greenhouse as compared to inside. Hippophoae rhamnoides survived at a higher rate when grown as tubelings in the greenhouse. Prunus tomentosa and Artemisia abrotanum survival rates were not significantly influenced by the two cultural methods.

Significantly more J. scopulorum and P. ponderosa plants were established when planted as tubelings as compared to bare-root stock. First-year survival rates for Prunus tomentosa were approximately equal for all three treatments. Artemisia abrotanum established significantly more plants when planted as bare-root stock. Most species demonstrated relatively high mortality rates between the first and second data collection period with greatly reduced mortality between the second and third data collection periods. Fraxinus pennsylvanica and A. abrotanum species, planted as bare-root stock, were exceptions to the above as they underwent only slight mortality rates during the three-year study period.

Table 38.6. Study II at the Pompey's Pillar, Montana study area. Survival (%) and plant height (cm) data for three plant species with two tubeling lengths. Species planted during late May 1974.

Species	61 cm x 16 cm Tubeling				30.5 cm x 16 cm Tubeling			
	Sept. 1974		Sept. 1976		Sept. 1974		Sept. 1976	
	%	cm	%	cm	%	cm	%	cm
Mountain snowberry	86xa	19.3	45a	35.2	72yb	22.2	52a	34.1
Antelope bitterbrush	76yab	12.5	29b	34.7	88xab	12.6	33b	37.1
Ponderosa pine	68yb	12.3	36ab	29.8	92xa	14.0	36ab	31.0

Source: Adapted from Jensen and Hodder (1979b)

Note: Comparable treatment means within rows for 61 cm long and 30.5 cm long tubelings followed by different letters (x-y) are significantly different from each other at the 0.05 level (Newman-Keul Test). Treatment means within columns followed by different letters (a, b and c) are also significant. Those treatment means not followed by letters indicate that the analysis of variance was not statistically significant.

Table 38.7. Study IV at the Pompey's Pillar, Montana study area. Survival (%) and height (cm) data for two tubeling cultural methods, two planting methods and six species. Species planted during late May 1974.

	Greenhouse grown tubelings				Outside grown tubelings				Bare-root stock			
	Sept 1974		Sept 1976		Sept 1974		Sept 1976		Sept 1974		Sept 1976	
	%	cm	%	cm	%	cm	%	cm	%	cm	%	cm
Rocky Mountain juniper	80ya*	15.5	69ya	21.5	90yab	16.4	79xa	21.3	44zc	17.1	22zd	31.2
Ponderosa pine	67yb	13.5	52yb	36.1	84xb	17.8	63xbc	41.0	48zc	12.8	27zd	38.9
Green ash	80ya	41.4	39yc	45.7	100xa	30.9	46yc	41.0	100xa	35.1	98xa	91.7
Sea buckthorn	87xa	17.4	40xyc	62.3	76yb	23.8	29yd	59.0	85xb	23.1	46xc	63.2
Nanking cherry	85a	16.5	53yb	37.4	87b	16.6	68xb	51.1	88b	21.9	62xyb	65.9
Oldman wormwood	79yab	30.4	50yab	67.9	85yb	26.5	67xyb	69.8	100xa	37.2	96xa	75.2

Source: Adapted from Jensen and Hodder (1979b)

* Comparable treatment means within rows for the tubeling cultural and planting methods followed by different letters (x to z) are significantly different from each other at the 0.05 level (Newman-Keul Test). Treatment means within columns followed by different letters (a to d) are also significantly different. Plant heights were not statistically analyzed.

From these three sub-studies, Jensen and Hodder (1979b) concluded that:

1. Several species benefited from the tubeling planting method, though the differences were not as great as expected.
2. For certain species, tubelings grown outside the greenhouse may tend to be more readily adapted to a harsh environment. The only major problem associated with growing tubelings outside is the extremely slow rate of growth and the danger of frost damage.
3. The shorter (30 cm) tubelings appear to be as effective as the longer (61 cm) tubelings for establishing plants when moist conditions prevail. Use of the shorter tubelings, if they will perform as well as the longer tubelings, is desirable because of lower cost and ease of handling and planting.
4. The most important consideration, when attempting to revegetate large areas, will be the individual establishment requirements for each species.

Barker and McKell (1979) compared the effects of container size and propagation method on pre-planting growth of Atriplex canescens and Sarcobatus vermiculatus grown in a greenhouse. Seedlings and stem cuttings of the two species were grown in four container types differing in size, shape, and ease of handling (Table 38.8).

The milk container, a one-quart (1L) paper carton, measured 7 x 7 x 24 cm with a volume of 1176 cm^3. The bottom of the container was sealed to prevent root egress, except for two small holes that were needed for water drainage.

A cylindrical ("deep") container was handmade from material called "cotton green" which is a mesh of cotton strands cemented between two clear plastic sheets. This container had a diameter of 5 cm and a length of 42.5 cm with a volume of 668 cm^3. The bottom of the container was open to allow air-root pruning and water drainage.

Tubepak 1 consists of units of five connected tubes made of semi-transparent, styrene plastic. Each tube measures 3.7 by 5.0 by

Table 38.8. Advantages and disadvantages of using the Milk, Deep, Tubepak , and Single Cell containers.

Container Type	Volume (cm)	Advantage	Disadvantage
Milk	1176	Large rooting volume Easy to plant seedlings & cuttings Sturdy Provides long term plant growth High root density Requires less frequent watering & fertilizing	Heavy when filled Bottom causes root spiraling Requires large bench space Poor water drainage
Deep	668	Plants develop a deep root system Provides long term plant growth Does not damage tap root Requires less frequent watering & fertilizing	Not self supporting Hard to obtain uniform water distribution Roots may spiral Hard to transplant from Low root density Root system may be damaged when transplanted
Tubepak	279	Encourages air-root pruning Water drainage is good Controls root growth Requires small bench space Sturdy Easy to transplant from High root density	Small rooting volume Hard to plant seedlings & cuttings in Becomes brittle Requires frequent watering and fertilizing
Single Cell	120	Encourages air-root pruning Water drainage is good Requires little bench space Controls root growth Sturdy High root density	Small rooting volume Hard to plant seedlings and cuttings in Hard to transplant from Root system may be damaged when transplanted Nutrients may leach excessively from the soil core Requires frequent watering and fertilizing

Source: Adapted from Barker and McKell (1979).

17.5 cm, has a volume of about 279 cm^3, and tapers to a hole at the bottom that permits air-root pruning and water drainage. Each tube unit has vertical ribs, directing roots straight down and thus avoiding spiralling.

R.L. Single Cell is a commercially available plant container made of opaque white plastic. This small cylindrical container has a diameter of 2.5 cm, a length of 16 cm, a volume of 120 cm^3, and tapers to a hole for water drainage and air-root pruning. Three vertical ribs, an equal distance apart, direct root growth downwards and prevent spiralling.

Plant materials for stem cuttings were collected 28 January 1977 in the oil shale region near Bonanza, Utah. Anticipating poor rooting from S. vermiculatus cuttings obtained in the field, stem cuttings were also taken from one-year-old seedlings maintained in the greenhouse.

All stem cuttings were collected from healthy mature plants using only the previous year's growth. After harvesting, the cuttings were stored in an ice chest and shaded from the sun until they were transported to the greenhouse. The stems were next cut into pieces 8 cm long, treated with indolebutyric acid (concentrations ranged from 0 to 2.0 percent IBA in talc), and stuck in moistened peat pellets. Plastic trays containing 100 cuttings were placed in a polyethylene enclosure, where a bottom heat of 23°C was maintained with heating pads. After four to six weeks, rooted cuttings were transplanted into the containers.

Seeds were collected from each species during the late fall of 1975 near Bonanza, Utah. After cleaning, the seeds were stored in paper envelopes at room temperature. Moistened paper towels in plastic germination trays were used for seed germination.

All A. canescens and S. vermiculatus seedlings and stem cuttings were planted 26 and 27 February 1977 in their assigned container types. The plant growth medium used in the containers was one-third soil, one-third sand, one-sixth peat moss, and one-sixth vermiculite by volume. Plants were fertilized weekly after the fourth

week and watered about every third day. The large containers, in contrast to the small containers provided a greater volume for root system growth and also required less frequent watering and fertilizing. Large containers, however, required more bench space than small containers.

Three randomly selected plants per treatment were harvested at four-week intervals for 20 weeks. Shoot length, shoot biomass, and root biomass were measured following each harvest. By the end of the 20-week period, shoot length, and shoot and root biomass were significantly lower in the Single Cell containers and significantly greater in the milk containers for both species (Tables 38.9 and 38.10). Shoot length of A. canescens was greater when planted as seedlings; however, S. vermiculatus stem cuttings showed greater shoot length (Table 38.11). Shoot and root biomass were greatest in planted seedlings for both species.

Barker and McKell (1979) described the root morphology that developed and noted that it was determined to a great extent by container type. The reader is referred to their publication for further details.

From this study Barker and McKell concluded that A. canescens and S. vermiculatus should be grown in the largest container possible (in relation to other constraints such as cost and handling) to produce healthy plants. They noted that if plants are to be held for long periods before field planting, again large containers should be used. On the other hand, small containers may be adequate if transplanting occurs within six weeks. Tall containers allow plants to develop long root systems which may be planted deeply, providing a small advantage in arid regions.

38.1.3 Other Geographic Regions

Negusanti (1978) compared the survival of Pinus banksiana seedlings planted as bare-root stock and as over-wintered seedlings in Japanese paper pots (Size 408). Both stock types were planted into a barren field near Sudbury, Ontario which had been subjected to SO_2

Table 38.9. Mean shoot length, shoot biomass and root biomass of fourwing saltbush plants harvested at four-week intervals while growing in four container types.*

Container Treatment	Weeks 4	8	12	16	20
Shoot length (cm)					
Milk	10.0 abc†	17.8 fg	34.5 hi	50.0 j	66.7 k
Deep	3.9 a	12.4 cdef	21.4 g	35.8 i	50.0 j
Tubepak	8.9 abc	11.5 bcdef	17.6 efg	16.7 defg	29.6 hi
Single cell	4.6 a	6.4 abc	5.9 abc	8.2 abc	7.8 abc
Shoot biomass (g)					
Milk	0.08 l	1.40 o	2.40 p	4.90 q	9.80 s
Deep	0.05 l	0.59 mn	1.10 no	2.30 p	5.60 r
Tubepak	0.08 l	0.78 mn	1.10 no	1.20 no	2.50 p
Single cell	0.03 l	0.36 lm	0.21 lm	0.35 lm	0.41 lm
Root biomass (g)					
Milk	0.02 t	0.18 tu	0.72 wx	1.80 z	4.30 b'
Deep	0.01 t	0.11 tu	0.46 uvw	0.87 x	2.20 a'
Tubepak	0.03 t	0.13 tu	0.34 tuv	0.67 vwx	1.30 y
Single cell	0.01 t	0.04 t	0.13 tu	0.28 tu	0.34 tuv

Source: Barker and McKell (1979)

* Means are the combined growth of both seedlings and stem cuttings.

† Means with the same letter are not significantly different at the 5 percent level.

Table 38.10. Mean shoot length, shoot biomass and root biomass of greasewood plants harvested at four-week intervals while growing in four container types.*

Container Treatment	Weeks 4	8	12	16	20
Shoot length (cm)					
Milk	4.3 abc†	9.6 fg	21.7 hi	37.8 j	44.9 k
Deep	5.2 abcd	5.9 abcde	14.5 g	22.2 h	29.3 i
Tubepak	3.5 ab	4.6 abc	7.7 bcde	13.7 fg	13.1 fg
Single cell	3.3 a	5.3 abcd	7.8 cde	13.5 fg	8.9 de
Shoot biomass (g)					
Milk	0.03 l	0.67 opq	1.40 st	4.30 y	3.50 u
Deep	0.03 l	0.13 lm	0.39 lmno	1.10 rs	2.10 t
Tubepak	0.02 l	0.43 mno	0.52 nop	0.82 pqr	0.90 qr
Single cell	0.02 l	0.07 lm	0.15 lmn	0.27 lmn	0.20 lmn
Root biomass (g)					
Milk	0.01 w	0.10 w	0.92 z	2.70 b'	2.10 a'
Deep	0.02 w	0.04 w	0.27 wy	0.61 yz	1.70 a'
Tubepak	0.01 w	0.13 wy	0.44 wyx	0.61 yz	1.70 a'
Single cell	0.06 wy	0.05 wy	0.14 wy	0.24 wy	0.21 wy

Source: Barker and McKell (1979)

* Means are the combined growth of both seedlings and stem cuttings.

† Means with the same letter are not significantly different at the 5 percent level.

Table 38.11. Mean shoot length, shoot biomass and root biomass of fourwing saltbush and greasewood seedlings and stem cuttings grown in four container types for 20 weeks.

Species Propagation	Shoot Length (cm)	Shoot Biomass (g)	Root Biomass (g)
Fourwing Saltbush			
Seedling	22.6 a*	1.90 m	0.89 x
Stem cutting	18.9 b	1.62 n	0.50 y
Greasewood			
Seedling	13.5 a	0.92 m	0.71 x
Stem cutting	15.2 b	0.78 n	0.44 y

Source: Barker and McKell (1979)

* Means with the same letter within each species are not significantly different at the 5 percent level.

fumigation and metal particle fallout for some time. Containerized stock outperformed the bare-root stock in terms of survival and growth (Table 38.12). Negusanti concluded that the Japanese paper pots may provide a successful alternative method of reclaiming many of Sudbury's deteriorated sites.

Goodman, Koppe and Hutnick (1977) compared the effects of various types of containers (styroblock, Spencer-Lemaire book planters, Japanese paperpots, multiple-seeding pots) on the establishment of one-year-old conifer seedlings on coal spoils in the eastern U.S. Results varied from excellent to complete failures. Seedlings grown in the multiple-seeding containers had nearly 100% mortality within a month or two after planting. Survival among sites for the Japanese paperpots varied from 29% to 74% and for Spencer-Lemaire book planters from 22% to 64%. Styroblock containers were used at one site and had a 67% survival rate. Commercial 2+0 bare-root stock did as well or better than all the container stock. Goodman, Koppe and Hutnick attributed the poor survival of container stock to the poor condition of root and shoot development of the seedlings at planting time and poor weather conditions following planting.

Davidson and Sowa (1974) reported on a four-year study of establishment and survival of Pinus resinosa seedlings grown in various containers and planted in Pennsylvania coal mine spoils. A preliminary study in 1968 tested the survival of ten-week-old P. resinosa seedlings in Ontario-type plastic tubes (7.6 cm long, 1.4 cm in diameter, 0.03 cm thick plastic, open at both ends, and split along the sides) as compared to 2+0 bare-root stock. At the end of the first growing season, survival was excellent for both. After the first winter, however, 84% of the tubelings had been frost-heaved, resulting in severe mortality.

Due to the poor results from the plastic containers Davidson and Sowa (1974) decided to test a variety of containers which were readily available:

1. Peat pots; 6.3 cm top diameter x 7.9 cm deep.
2. Jiffy-7's; compressed peat pellets, 4.4 cm high x 4.4 cm diameter when saturated.

Table 38.12. Assessment of survival and growth of *Pinus banksiana* planted as bare-root and containerized stock, Sudbury, Ontario.

Planting Method	Second Year	
	Survival (%)[a]	(Growth %)[a]
Bare-root	80.5	40.5
Paper pots	90.6	157.3

Source: Adapted from Negusanti (1978).
[a] Values are arithmetic means of three lime and fertilizer treatments.

3. Asphalt tubes; 5.1 cm diameter x 10.2 cm long, fabricated from 15-lb felt building paper.
4. Conwed large perforated plastic tubes; 2.5 cm diameter x 15.2 cm long.
5. Conwed small perforated plastic tubes; 1.6 cm diameter x 15.2 cm long.
6. Ontario plastic tubes; (previously described, used this time as controls).

Ten P. resinosa seedlings from each container type were planted as two-month-old or three-month-old stock and ten 2+0 bare-root nursery stock seedlings were planted for comparison. Three planting sites were used:

1. anthracite coal-breaker refuse, pH = 3.4, black, highly pyritic mixture of carbonaceous shales and coal fragments;
2. bituminous coal-breaker refuse, pH = 3.0, material as above; and
3. bituminous strip-mine spoil, pH = 3.5, acid sandstone and black pyritic material.

After the first growing season no differences were found between the two- and three-month-old seedlings so the data were combined. Bare-root stock did as well or better than container stock at all sites. A great deal of variability in survival data with no consistent trends was evident after the first year (Table 38.13). In the first winter, the anthracite refuse site was destroyed; therefore, it does not appear in further results. By the end of the third growing season it became evident that the Conwed and Ontario-type plastic containers were susceptible to frost-heaving (Table 38.13) and thus not suited to revegetation of bituminous coal mine spoils. The seedlings in peat pots did best on the coal-breaker refuse while bare-root stock did best on the strip-mine spoil (followed by peat pots and Jiffy-7 containers). Davidson and Sowa (1974) concluded that the larger containers have more potential for establishing vegetation on coal mine spoils. The peat pots and Jiffy-7's were particularly effective because they provided space for adequate root development.

Table 38.13. Average survival and height growth[a], after three years, of container-grown Pinus resinosa seedlings planted on coal spoils in Pennsylvania.

Container	Coal-breaker refuse			Strip-mine spoil		
	Survival %	Total height cm	1972 height growth cm	Survival %	Total height cm	1972 height growth cm
Peat pot	59	9	3	78	27	20
Jiffy-7	28	7	2	73	21	15
Asphalt tube	16	8	3	40	23	17
Large perforated plastic	14	13	3	45	21	13
Small perforated plastic	0	--	--	20	20	9
Ontario tube	0	--	--	38	13	7
Average	20	9	3	49	22	15
Bare root seedlings	38	21	5	90	35	17

Source: Adapted from Davidson and Sowa (1974).
[a] Weighted averages.

Balmer (1976) reported on a test of various containers in Florida. Pinus caribaea was planted into clay spoils using plastic bullets, Jiffy-7's, speedlings, and paper pots, with bare-root seedlings as a check. At the end of one growing season bare-root stock had fared poorly due to "J" and "L" shaped root orientation. Paper pots gave the best height growth and root development and had 90% survival. Speedlings had slightly better survival (95%) but slightly poorer growth. The poor performance of the plastic bullet (57% survival) was due to shattering during planting or failure to split open and allow root egress. Both paper pots and speedlings allowed plants to develop a large root mass which enhanced the chances of survival.

38.2 BARE-ROOT STOCK

Tiedemann et al. (1976) and Schessler and Bergoffen (1964) noted that proper care of bare-root stock is essential in reclamation work. Only dormant plants should be used and planting crews should take to the field only the number of plants that can be planted in one day. Excess stock should be returned to cold storage and be planted first the next day. Bare-root stock has less need for hardening off because it is packed and planted when dormant (USDA, Forest Service 1979). Richardson, Shenton and Dicker (1971) also found a great deal of benefit in quick transfer of nursery stock to its permanent place on site. They noted that taking small batches of trees directly from the nursery to the site eliminates the need for "heeling in" plants, assists in quick establishment, and also eliminates the delay and cost of replacing stock which dies. Draves and Berg (1979) noted that the single most important factor affecting seedling survival is the condition of the stock as it comes from the nursery.

Tiedemann et al. (1976) noted that seedling size is important. When planting on slopes of loose material, the stems must be tall enough to survive inundation by loose soil material. Richardson, Shenton and Dicker (1971) found that the ideal sapling for planting on colliery spoil in England was probably about 0.9 m tall and possessed a well developed root system. Tiedemann et al. (1976), however, mentioned that

a small root system will allow easy planting on sloping areas with a minimum of disturbance. Baker (1978) reported on the use of Salix and Populus poles 2 to 5 cm in diameter and 1 m tall to stabilize scree in New Zealand. Poles were planted to a depth of 60 cm using a drill inside of a hollow tube. The seedling was placed in the tube after the hole had been drilled.

Pruning trees and shrubs helps reduce transpiration losses and improves the root:shoot ratio. This is especially important at planting time when new root growth is just beginning (Richardson, Shenton and Dicker 1971).

DePuit, Coenenberg and Willmuth (1978) found that the prime cause of planting failure in their bare-root planting trials at Colstrip, Montana was a non-vertical ("J") terminal root orientation. This was due to the planting holes being too shallow, and the authors stressed the need for adequate hole sizes for planting. Balmer (1976) also indicated major problems in hand or machine planting of Pinus caribaea in Florida because of "J" or "L" root orientation.

Selner and Thompson (1977) studied the effects of two planting methods on establishment of Acer negundo on a waste dump site composed of a mixture of overburden material removed during mining at the Suncor site. The first planting method used the Swedish Tree Planting Mattock which reputedly provides the best planting hole preparation for critical conditions. First an area 25 to 35 cm in diameter was scarified to remove vegetation, then a hole approximately 20 cm deep and 17 cm in top diameter was dug, and the seedling placed in the hole. The soil was then firmly packed to eliminate air pockets and bring roots into close contact with the soil. This method is effective but very time consuming.

The second series of trees were planted with a planting bar. According to the manufacturer, the planting bar was developed to plant small seedlings in sandy soils and is one of the fastest methods available. In this method, a slit is made in the ground and the seedling is inserted. The slit is then closed and the soil packed around the roots.

At the end of one growing season, there was no difference between the planting methods in survival or vigour of the plants. The authors noted, however, that stock was small (15 cm), had small root systems, and was planted late in the season. These factors reduced the survival of the trees (to 12 to 17%) and may have masked any effects dependent upon planting method.

Selner (1973, 1974) compared the establishment of bare-root and containerized Picea glauca in three alpine areas of Alberta. Between 10 May and 17 May 1973 fifteen plots were established on coal spoil piles at Lovett, Coal Valley, and Sterco in the Edson Forest. From 26 May to 01 June, 30 plots were established at Tent Mountain and Grassy Mountain in the Bow/Crow Forest. Plots were inspected in early August of the same year and data were collected on percent survival and quality of stock (Table 38.14). The bare-root stock had a greater survival rate in all areas; however, Selner expected mortality to be high during the winter.

Orr (1977) compared the effects of container versus bare-root stock on the establishment and growth of seven species (Table 24.3) planted in sandy clay loam coal spoils in an arid region of Wyoming. By the end of the first growing season there was no overall difference in percent survival between the container and bare-root stock (Table 24.3). There were, however, significant differences in the way individual species reacted. The two deciduous species, Fraxinus pennsylvanica and Elaeagnus angustifolia, had much higher survival rates when planted as bare-root stock while Pinus ponderosa did much better as container grown stock. By the end of the first winter the overall difference between stock types was significant. Bare-root survival was greater for four of the five deciduous shrubs, but container grown coniferous stock performed better than bare-root stock.

Goodman, Koppe and Hutnick (1977) studied the effects of container type on establishment success for pine species planted on coal spoils in the eastern U.S. They used 2+0 bare-root nursery stock as a control. After one growing season they found that the bare-root stock

Table 38.14. Percent survival and stock quality of Picea glauca planted as bare-root or container stock in the Edson and Bow/Crow Forests, Alberta.

Parameter	Planting method	Edson[a]	Bow/Crow	
			Tent Mtn.	Grassy Mtn.
% Surviving and healthy	Bare-root	92.6	89.5	65.8
	Container	71.8	72.0	39.0

Source: Adapted from Selner (1973).
[a] Values are aritmetic means of data from three sites: Lovett, Coal Valley, and Sterco.
[b] Includes plants which were likely to die in the near future.

outperformed the one-year-old containerized seedlings on a variety of surface mined sites. They attributed this success to the extra year's growth of the bare-root stock.

Finn (1958) tested the effects of planting method on the establishment of 2+2 Pinus strobus on a strip mine bank in eastern Ohio. The three methods tested were: (1) the side-hole method using a grub hoe or a mattock, (2) the centre-hole method using a mattock to dig the hole and a tamper to pack the soil around the roots of the planted trees, and (3) the bar-slit method. The latter was the cheapest of the three planting methods tested and differences in survival and growth rates did not justify the use of the other two methods (Table 38.15). The bar-slit method would be ineffective only if the surface material was very hard or contained a high percentage of rock, making insertion of the bar difficult.

38.3 OTHER PLANTING METHODS

Wildlings are especially useful when a species adapted to a mine site does not produce a good seed crop. They also provide immediate vegetative cover (USDA, Forest Service 1979).

Campbell and Scotter (1975) studied the effect of plug size on the establishment of Luetkea pectinata in disturbed alpine sites in Mount Revelstoke National Park, British Columbia. Disturbances consisted mainly of road-cuts and old building locations. Plugs of three sizes (3 x 5 cm, 7 x 10 cm, 15 x 20 cm) were planted at 50 cm intervals in 140 plots during both the spring and summer. Plots were assessed at the end of August in the first growing season. They found that the larger plugs showed higher survival rates than did the smaller ones, especially under conditions which were less than ideal for plant survival. They noted, however, that the smaller plugs were easier to obtain, transport, and handle. Scotter (1976) re-examined the plots in September of the second growing season and found similar trends.

Hodder (1973, 1977) discussed the use of "supplemental root transplanting" as a method of reclaiming strip mines in dryland regions

Table 38.15. Effect of planting method on the survival and growth of *Pinus strobus* planted in Ohio after five years.

Planting Method	Site I (Clay and limestone)		Site II (Acid-silt, shale and sandstone blocks)	
	% Survival	Height(cm)	% Survival	Height(cm)
Bar-slit	81	54.9	43	70.1
Mattock and tamper	80	48.8	64	67.1
Side-hole mattock	56	51.8	35	48.8

Source: Adapted from Finn (1958).

of Montana. Supplemental root transplanting is accomplished by carefully removing a pair of interconnected seedlings of a rhizomatous shrub species. The top of one seedling is pruned off at the crown, leaving two root systems connected to the uncropped seedling. The horizontally connected root systems are then placed in a vertical attitude, one being placed down in the deep soil moisture and the other placed in a normal manner in the drier soil surface (Figure 38.3).

Draves and Berg (1979) advocate the transplanting of mature shrubs to act as "seed trees". These transplants can be used to establish islands of seed producing shrubs on a revegetation site. Besides acting as propagation nuclei, the islands may also serve as cover for wildlife. Draves and Berg placed mature transplants of Amelanchier alnifolia, Prunus virginiana, and Symphoricarpos oreophilus on an alpine coal spoil in Colorado. At the end of the third growing season, A. alnifolia exhibited the greatest vigour of all species; 73% of the survivors had bloomed and set seed.

Jensen and Hodder (1979b) evaluated the practicality of mature tree transplants for reclamation of roadside sites in arid regions of Montana. Six trees each, of five species (Table 38.16), were carefully excavated with a tree spade, the roots tightly wrapped in polyethylene and burlap, and transported to the planting site. On site, a hole was dug for each tree. Prior to planting, 38 L of water was poured into the bottom of each hole to help form an air tight seal between tree roots and surrounding soil. Trees were pruned prior to placement in the hole. Each tree was watered with 95 L of water and a 6 mil thick, black polyethylene sheet having a radius of 2.4 m was placed around the base of each tree. Five centimetres of coarse gravel were placed on the sheet to secure it in place. After high winds tipped the first few trees, guy wires were used to secure the rest in position. Upon completion of planting, trees were given a final pruning. Deciduous species had approximately 40 to 50% of the leaf bearing branches removed to help compensate for the reduced root size. Trees were watered during the first growing season.

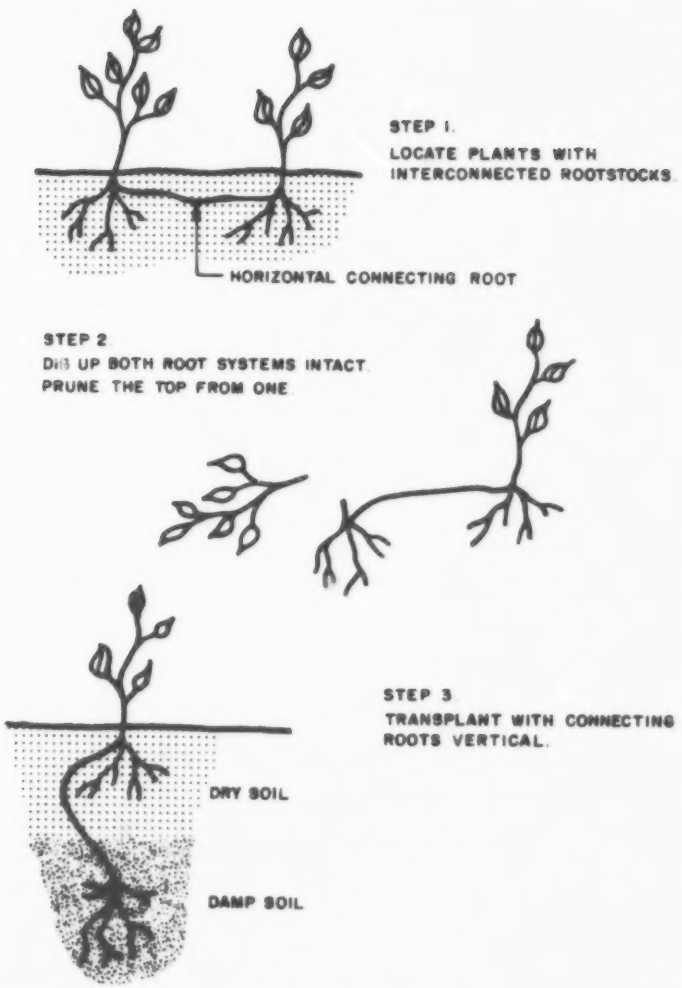

Figure 38.3. The supplemental root system of dryland planting allows roots to be placed at both deep and normal depths.

Source: Hodder (1973:72)

Table 38.16. Percent survival and average vigour rating of surviving trees for five species planted during the spring and fall of 1971 at the Pinehills Interchange, Montana. Data collected on five dates.

	June 1972				September 1976				May 1978			
	% Survival		Avg. Vigour		% Survival		Avg. Vigour		% Survival		Avg. Vigour	
	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall	Spring	Fall
Ponderosa pine	100	100	4[a]	3.7	100	66	4	3	66	66	3	2
Rocky Mountain juniper	100	100	3.7	3	100	66	3	3	66	66	2	2
Russian olive	100	100	3	4	66	100	3	3	66	100	3	3
Boxelder	100	100	3	3.3	33	33	2	2	0	0	ND	ND
Plains cottonwood	66	100	2.5	4	0	0	ND	ND	0	0	ND	ND

Source: Adapted from Jensen and Hodder (1979b).

[a]Average vigour rating: 2 = poor, 3 = fair, 4 = good, and 5 = excellent.

Survival was high throughout the seven-year study period for the two conifers and for the Elaeagnus angustifolia (66%). Survival of Acer negundo and Populus deltoides declined throughout the period and all were dead by the seventh season (Table 38.16). Vigour declined in all species over the study period.

A front-end loader has been successfully used for digging up and moving pads of shrubs or trees, such as Populus (USDA, Forest Service 1979). The pads must be replanted in an upright position, and guy wires may be necessary to anchor the trees. Because these trees will attract wildlife, it may be necessary to fence them until they are well established. Tresler (1974) has also had success using this method for revegetating coal mine spoils in Wyoming.

Jensen and Hodder (1979b) noted that survival may have been increased if smaller trees had been used. They also suggested that potential transplants should be root pruned a year or more in advance. This would force the tree to develop functional root systems within the root mass, to be excavated before transplanting takes place.

They have also examined the use of shrub root sprigging as a method of establishing slow growing plants in arid regions. The authors chose a sandy gravel, south-east facing slope (3:1) at the Colstrip Interchange, Montana to test the method using three strongly rhizomatous species.

The first step in root sprigging is to locate sources of desirable plant material on terrain suitable for equipment operation. Next a flail or rotary type mower, suitable for cutting brush, is used to remove top growth to within 15 to 20 cm of the soil surface. The remaining top growth and rhizomatous root systems are then excavated with an agricultural type plow or similar implement and a front-end loader. In this study, the soil and root system mass was hauled without any effort to separate the two. The root soil mixture was then transported by dump truck to the planting site where it was pushed down the slope and uniformly spread over the plot area. The plot was then completely covered with a 10 cm layer of sandy soil. Planting was

completed by 06 November 1971. Shrub sprout frequency data were collected for two growing seasons.

Dense stands of shrub shoots were evident by mid-May of 1972. Rosa woodsii and Symphoricarpos albus established good stands by June of the first growing season. Initial data showed that Salix was not adapted to arid land planting. By June of the second growing season, Salix had died out and shoot frequency was reduced in the other two species. Following a prolonged, hot, dry summer in the third growing season, all plants were dead.

Jensen and Hodder attributed the failure of the three species to the harsh site characteristics and not to shortcomings in the sprigging technique. For this reason Jensen and Hodder (1979a,b) initiated a second planting of Rosa woodsii and Symphoricarpos in December 1972 on a north-west facing slope. Soils on the new site were more favorable as they had a sandy clay texture, improved moisture conditions, and the site also received additional water from roadway surface runoff.

Roots of the two shrub species established excellent stands during the spring and continued to maintain excellent shoot frequency (Table 38.17) throughout the summer despite extremely dry conditions. Field observations in May 1978 revealed dense stands of vigorous Rosa and Sympharicarpos bushes.

Jensen and Hodder (1979b) concluded that root sprigging is a rapid and easy method of establishing shrubs in arid regions, provided species are established in areas compatible with their growth requirements.

38.4 CUTTINGS

The propagation of plants through tip and hardwood cuttings is the oldest method of propagation used for the revegetation of mineral soils (Schiechtl 1980). Cuttings are also one of the easiest and cheapest methods of reclamation (Selner 1973).

Schiechtl (1980) noted, however, that there are several important differences between greenhouse propagation and direct planting

Table 38.17. Average frequency of shrub shoots (50 cm^2 quadrat) at the Colstrip Interchange, Montana. Data were collected on two dates for two shrub species.

Common Name	Scientific Name	Average frequency of shoots per 50 cm square quadrat
		September 1973
Rose	Rosa woodsii	88.9%
Snowberry	Symphoricarpos alba	80.6%

Source: Adapted from Jensen and Hodder (1979b).

of cuttings for reclamation. The selection of cuttings from exceptionally healthy mother plants, for example, can rarely be achieved because of the need for a great number of cuttings. It is also impossible to control the temperature of the outdoors, and rarely can one influence the properties of the propagation substrate, or the humidity and soil moisture conditions at the planting site.

Schiechtl (1980) also noted that there is great deal of variation in the preferred length, diameter, and age of cuttings used in reclamation work. He reported on the success of cuttings the size of a pencil and the use of Salix poles up to 4 m long. Schiechtl (1980:182) suggested the following rules when choosing cutting thickness: "...the thickness of the cutting is limited only by practicality and profitability (transportation and other costs), and by the supply available from natural plant communities or nurseries. Therefore, cuttings up to the size of a man's arm, and in a few cases, even larger can be used. Small, flexible branch tips should be mixed with stronger, older branches. If possible large branches should be used, but very often it is necessary to use the material sparingly because it may be in short supply. This is very seldom the case in Canada, especially in northern Canada...."

Selner and Thompson (1977) tested the effect of cutting size on the survival of Populus balsamifera on a peat amended tailings dike and an overburden dump at the Great Canadian Oil Sands Company (now Suncor) lease near Fort McMurray, Alberta. The cuttings were taken from the main stem of Populus saplings found along the Athabasca River bank. Two basic types of cuttings were collected. The first was a large size cutting, 80 to 130 cm long and 1.5 to 7 cm in diameter. The cuttings were delimbed and planted in trenches a shovel width wide and 50 to 80 cm deep. The cutting was placed in the trench at an angle so that only 2 or 3 cm would be above ground level when the trench was filled in. The second type of cutting was 15 to 20 cm long and 0.5 to 1.5 cm in diameter with both ends cut at a slight angle. The cuttings were forced into the ground as far as possible at a 30° to 40° angle and then

the remaining portion was cut off at ground level. On both sites, the larger cuttings performed better than the smaller type by the end of the first growing season (Table 38.18). The authors attributed this success to the greater reserve of energy in the larger cuttings which would be available for developing shoots and roots. They also noted, however, that the larger cuttings were planted at a greater depth which may have given them an advantage due to improved moisture conditions for rooting.

Plummer (1974) found that 25 to 46 cm long cuttings from Artemisia abrotanum stems, 0.3 to 1.3 cm in diameter, gave better results than smaller cuttings in alpine areas of Utah. Plummer noted that the smaller cuttings were difficult to stick in the ground and suggested sharpening the large end to facilitate penetration of a hard soil surface.

Leiser et al. (1974) found that cutting diameter had an effect on the survival of Salix lemmonii cuttings planted on a granite rock cut in an alpine region of California. Cuttings with a diameter between 0.95 and 1.3 cm had greater percent survival after two years (23%) than did larger cuttings (1.9 to 2.5 cm; 7.5% survival) or smaller cuttings (0.5 to 0.6 cm; 3.5% survival). The use of a rooting hormone (indole butyric acid IBA) caused a decrease in establishment rate (13.7% control versus 9% IBA).

Chosa and Shetron (1976) studied the effects of cutting size on the establishment and survival of Salix planted around an iron mill waste pond in Michigan. Cuttings varied in size from 1.3 cm up to 10 cm in diameter and ranged from 0.3 to 1.8 m in length. Cuttings were inserted into the pond slimes 15.2 cm or more, using a 0.9 x 1.2 m spacing. Survival after one year was better than 80% with most of the mortality occurring in the smaller diameter cuttings. The authors presumed this was due to the smaller cuttings drying out and dying before their roots could become established. The 1.8 m cuttings fared as well or better than the 0.3 m cuttings.

One-year-old rooted cuttings, planted on a peat amended tailings dike and an overburden dump in the Oil Sands (Selner and Thompson 1977), had a much greater survival and growth rate

Table 38.18. Survival and growth of poplar cuttings after one growing season at GCOS, Fort McMurray, Alberta.

Cutting Type	Survival (%)		Growth (cm)	
	Tailings Dike	Waste Dump	Tailings Dike	Waste Dump
Large cuttings	26	12	42	18
Small cuttings	6	0	12	0
One-year-old rooted cuttings	61 96[a]	96	8 49[a]	20

Source: Adapted from Selner and Thompson (1977).
[a] Cuttings planted on peat amended tailings dyke.

(Table 38.18), indicating that rooted cuttings may be more useful than direct planting of cuttings. Macyk (1976) found that rooted cuttings of Salix spp. and Populus balsamifera performed better than unrooted cuttings planted in coal spoils in Grande Cache, Alberta. At the end of the first growing season the rooted cuttings had 70% survival while the unrooted cuttings had 40% survival. Macyk noted that the unrooted cuttings required more moisture and exhibited much less growth in the first few years than did the rooted cuttings. In 1977 the success of direct planted cuttings was much higher (70%), probably due to a much wetter spring. Rooted cuttings still did better with 80% survival.

Schiechtl (1980) discussed the importance of cutting placement in terms of root and shoot growth. Cuttings placed almost horizontally always produced a greater root and shoot mass than did those placed vertically. However, Lesko (1974) found no apparent effect of planting technique on the survival of Salix poles, 2.5 to 5 cm in diameter, planted vertically or obliquely on four topographic positions of a sand dune near Lesser Slave Lake, Alberta. The Salix pole cuttings survived much better (60%) than Salix twig cuttings (10%) planted at the same time.

38.5 SUMMARY

Container stock provides the following advantages: (1) better root form; (2) seldom requires pruning; (3) minimal disturbance in handling; (4) minimal damage to fine roots in handling; (5) immediate nutrient and moisture supply upon planting; (6) mycorrhizal infection; (7) faster production time; and (8) flexibility of planting operations.

Disadvantages include: (1) high cost of production; (2) higher shipping and handling costs; (3) frost heaving; and (4) subject to root restriction.

Advantages of bare-root stock are: (1) stock is handled while dormant; (2) there is less need for hardening off; and (3) handling problems (other than care of stock) are less than for container stock.

Disadvantages include: (1) stock must be handled very carefully; (2) field storage is more critical; (3) stock condition is critical; and (4) poorer root form than container stock after planting.

While it has been stated that container stock survival generally exceeds that of bare-root stock, the literature reviewed here has not definitely supported that conclusion. A more correct statement might be that containers are better for coniferous stock while deciduous species fare better as bare-root stock. Containers may be better for less hardy species on harsh sites. Comparisons vary with age and size of stock, container size and type, site conditions, handling and planting methods, and species.

Generally larger containers provide better survival and growth, but increase handling problems and cost. Tubeling lengths beyond 30 cm do not provide additional benefits except in extreme circumstances. If stock is held in containers longer than six weeks before planting, large containers should be used.

Many types of containers are available. Tough, non-biodegradable containers tend to restrict root systems and increase the risk of frost heaving.

The literature would indicate that researchers are perhaps not aware of the vast forestry literature available on the subject of planting. Many of the problems noted in the reclamation literature have already been identified and solved, particularly for coniferous stock. There is a need for more research in production and planting of deciduous stock in small (less than 500 cc) containers.

A number of specialized planting methods have been used in reclamation, including supplementary root planting, plugs, island ecosystems, mature shrubs as seed trees, mature trees, and root cutting/soil mixes. These techniques may be time consuming and costly but are possibly suitable for localized specific problem areas.

Planting of stem cuttings has proven to be a very practical reclamation technique. There is great variation in the preferred length, diameter, and age of cuttings. Larger cuttings often perform best but availability, transportation, and planting can be limiting practical problems. Hardwood or softwood cutting may be used. Rooted cuttings are often more successful than unrooted cuttings. Cuttings may be planted

vertically or horizontally. No clear superiortiy has been demonstrated for either method.

More research is required on collection, handling, and planting of cuttings of various promising reclamation species in Alberta and elsewhere.

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39. TOPSOILING AND MULCHES FOR ESTABLISHMENT OF TREES AND SHRUBS

39.1 TOPSOILING

Williamson and Wangerud (1980) studied the effects of topsoil depth on survival and growth of trees planted on coal spoil slopes near Bismark, North Dakota. The study site was set up from May to July on a newly graded and topsoiled slope. The plots destined for thicker soil had the topsoil removed, were trenched to the specified depth, backfilled with subsoil, and had the topsoil replaced using Caterpillar wheeled scrapers.

Plots were designed to test three species of tree stock on north-east facing and south-west facing slopes having different soil depths. All A plots (Table 39.1) utilized 0.6 m tall potted Juniperus scopulorum and 1.2 m tall bare-root deciduous stock. The B plots were planted with 0.6 m tall potted Juniperus and 1.2 to 3.0 m tall bare-root deciduous stock.

The two deciduous species used were Fraxinus pennsylvanica, and Prunus americana. All plants were commercial nursery grown stock.

The trees were planted in June and early July 1978, following a late rainy spring that delayed earthwork. The stock was kept refrigerated and prior to planting was pruned, roots were dipped in mud slurry for protection against exposure, and tops were dipped in antidessicants. Planting holes were thoroughly watered and fertilized at the time of planting. A 0.9 m diameter basin was shaped at the base of each tree, filled with straw mulch, and covered with jute netting to aid moisture conservation. The larger trees were wrapped and staked down for protection against intense sun and wind. All plots were irrigated at a rate of 75 L (estimated) per plant per week during the first growing season and 3.8 L during the second season. Post-planting weed maintenance consisted of low mowing with hand-operated "weed eaters".

Data on percent survival and average crown height and diameter were taken in September of the second growing season (1979). There

Table 39.1. Survival and growth data for three tree species growing on coal spoils amended with three depths of topsoil, Bismark, North Dakota.

Soil Depth cm	Plot No.	Survival (%)			Diameter (mm)			Height (mm)			Crown (mm)		
		Gr Ash	Plum	Jun[a]	Gr Ash	Plum	Jun	Gr Ash	Plum	Jun	Gr Ash	Plum	Jun
30.5	A3	95	100	ND[b]	7	5	ND	344	ND	ND	ND	ND	ND
76.2	A1	60	80	100	5	0.5	5	229	ND	14	ND	146	167
	B2	70	75	85	3	2	8	120	ND	38	ND	163	80
152.4	A2	70	60	100	4	2	6	183	ND	44	ND	233	130
	B3	90	85	100	2	2	8	95	ND	65	ND	273	140

Source: Adapted from Williamson and Wangerud (1980).

[a] Green Ash, plum, and juniper.

[b] Data not available.

was no consistent response of either survival or growth to topsoil depth in this experiment (Table 39.1). Williamson and Wangeruc pointed out that the best growth of both Fraxinus and Prunus was achieved on the plots with the least topsoil.

Howard, Schuman and Rauzi (1977) collected random samples of topsoil and newly exposed overburden from two coal mines and a uranium mine in Wyoming. The materials were ground and mixed prior to the greenhouse experiments. The pretreatment pH and EC of the topsoil and overburden have been presented in Chapter 33.

Tests with woody plants were conducted using newly germinated seedlings of the native species Ceratoides lanata, Chrysothamnus nauseous, Atriplex canescens and Artemisia cana, and of the introduced species Halimodendron halodendron. These five shrubs were selected because of their adaptability to semi-arid conditions and because of seed persistence after ripening. Randomized, replicated plantings were made in 7 cm pots containing either topsoil from each of the mine sites or overburden or topsoil:overburden (1:1) mix. Fertilizer treatments for the pots in each test included an untreated control and 67 kg/ha of N or P alone or in equal combination. Plant height data were collected to evaluate growth.

When fertilizer treatment results were combined, the mean shrub height significantly increased in mine overburden amended with topsoil (Table 39.2), though individual species reacted differently to the treatments. Mean height of shrubs grown in topsoil alone was significantly greater than in overburden or the overburden:topsoil mix at the Seminoe Mine. At the Wyodak and Utah International Mines, topsoil improved growth only over the overburden.

Hodgson and Buckley (1975) and Hodgson and Townsend (1973) have demonstrated an improvement in establishment and early growth of trees and shrubs planted on amended pulverized fuel ash (PFA) in England. Sixteen species were planted on PFA, soil, acid shale, and PFA amended with either shale or soil. Mean height of the plants was measured $2\frac{1}{2}$ years after planting. Adding shale or soil to PFA improved the growth of all species, although soil tended to be a better

Table 39.2. Mean height of five woody species grown on coal spoils from three mines in Wyoming.

Mine and treatment	Height (cm) Winter-fat	Salt-tree	Rabbit-brush	Fourwing saltbush	Silver sage	Mean	
Seminoe No. 1							
Topsoil	14.3[a]	26.2	28.8	20.4	5.0	18.9	a
Overburden	11.9	5.4	14.5	7.0	5.4	8.8	f
1:1 mix	12.3	18.6	20.2	9.6	4.5	13.0	cde
Wyodak							
Topsoil	14.2	36.3	22.4	11.3	4.6	17.7	ab
Overburden	8.5	8.9	16.1	8.2	4.6	9.3	c
1:1 mix	10.9	20.9	26.5	8.5	5.8	14.5	bcd
Utah International							
Topsoil	9.3	18.9	22.3	17.0	5.1	14.5	bcd
Overburden	7.0	13.0	14.4	6.7	5.7	9.4	ef
1:1 mix	7.0	35.8	23.0	8.7	5.3	16.0	abc

Source: Adapted from Howard, Schuman and Rauzi (1977).
Note: Means followed by the same letter do not differ at the 5% level of probability by Fisher's method.
[a] Single plot means from four fertilizer level reps.

ameliorant (Table 39.3). The mixture of soil and ash appeared to provide a medium as satisfactory as the soil alone for some species. Combining acid shale with the PFA helped reduce pH to a near neutral level and lowered the boron content, thus providing an improved growth medium.

Hodgson and Buckley (1975) examined the "pocket planting" technique in which trees are given topsoil only in the immediate vicinity of the stem. This method should reduce the cost of "blanket" topsoil applications. Two experimental PFA sites in England, differing in boron content and degree of consolidation, were chosen. The ash at Stourport had been dumped dry to a depth of 4.5 m on low-lying marshy land and was very hard below a loose friable 10 cm surface. Ash at Dunston was disposed of by lagooning. Consolidation therefore was less severe than at Stourport. Stourport ash contained 100 ppm of available boron and Dunston ash 14 ppm.

Six common British species were chosen for study but data were presented for Picea sitchensis and Populus robusta only. The planting technique required drilling holes with a tractor-powered 30 cm diameter auger to a depth of 40 cm; a task that was easily accomplished at Dunston but was extremely difficult at Stourport because of indurated ash. The trees, 1+1 transplants or one-year-old rooted cuttings were then planted in the auger holes which had been back-filled with either ash or soil. Planting distances were 1.1 x 1.1 m, each main plot consisting of five 16.5 m rows of trees. The experimental design was a randomized block with four replications; species forming the main plots and the ash and soil comparison incorporated as a split plot treatment. A third factor, with or without a ground cover of Trifolium repens cv. S. 100, was also included in the design. Two blocks were undersown with inoculated seed in the same year the trees were planted at Stourport but two years after the plots were established at Dunston. The Dunston site was planted April 1966 with the Stourport site following in March 1968. All plots were fertilized at or soon after planting. Height measurements were taken each fall beginning in 1968.

Table 39.3. Mean height (cm) of 16 species 2½ years after planting on five growth media in England.

Species	PFA (pH 8.9)	Acid Shale (pH 3.3)	PFA + 15 cm acid shale	PFA + 15 cm soil	Soil (pH 7.8)
Alnus glutinosa	94	137	185	256	178
Crataegus oxyacantha	ND	ND	45	113	89
Elaeagnus angustifolia	121	ND	135	143	119
Euonymus europaeus	ND	ND	31	50	65
Forsythia ovata	ND	61	52	82	129
Fraxinus americana	47	59	72	112	136
F. excelsior	34	ND	55	76	174
Hippophae rhamnoides	130	ND	121	155	173
Ligustrum vulgare	33	ND	36	116	139
Picea excelsa	25	32	36	44	36
P. sitchensis	43	69	84	59	47
Populus nigra italica	163	ND	318	333	353
Robinia pseudoacacia	118	121	147	171	211
Salix britzensis	86	ND	109	166	204
Syringa vulgaris	37	ND	67	95	106
Ulmus glabra	51	ND	108	180	216

Source: Adapted from Hodgson and Townsend (1973).

Incorporation of soil improved survival of Picea at both sites but had no effect on Populus at the Dunston site. Survival of Populus in soil, however, was four times that of Populus not in soil at the Stourport site (Table 39.4). Figure 39.1 shows the same trends for the annual growth of both species.

From these data the authors concluded that the "pocket planting" technique could be used to improve species survival and growth but that the benefits were species and site specific.

39.2 MULCHES

39.2.1 North-east (Oil Sands) Region

The following studies have been included in this section as the substrate material is similiar to that found in the Oil Sands region. Sandy soils, such as those common to this region, are susceptible to erosion and therefore require immediate stabilization. The use of amendments such as mulches improve the chances of plants establishing by providing extra moisture in the droughty substrate.

Sharp and Hawk (1977) performed four experiments to test peat moss as a mulch for establishing one- or two-year-old bare-root shrub seedlings on coastal dunes near Lewes, Delaware. Peat moss was incorporated into the sand where the plant was to be placed by excavating a hole 25 x 25 cm, then filling it with 2 L of moss. Sand was also mixed with the peat.

In the first study, one set of plots was mulched in the fall and planted in fall or spring and another set was mulched and planted in the spring. Species tested were Rosa rugosa and Myrica pennsylvanica. In general, mulch improved second season survival (Table 39.5), growth, and vigour for both species. Rosa rugosa survival was improved by a fall mulching and planting technique while M. pennsylvanica benefited from either fall or spring mulching and planting. By the eighth growing season the mulched plants still had a higher survival rate.

In the second experiment, plots were mulched in the fall and four species planted in spring (Table 39.6). The effect of the mulch

Table 39.4. Percent survival of trees planted on PFA in England.

Species and Location	Dunston (six years)	Stourport (four years)
Populus - soil	88.0	80.0
- PFA	90.0	21.2
Picea - soil	59.4	57.4
- PFA	36.8	35.8

Source: Hodgson and Buckley (1975).

Table 39.5. Effect of mulch on second season survival (%) of two species planted into a coastal sand dune in Delaware.

	Mean Survival			
Treatment	Rugosa Rose		Bayberry	
Mulch[a]	46		61	
No mulch[b]	36		43	
Planting Season	Mulch	No Mulch	Mulch	No Mulch
Fall[c]	72	31	69	33
Spring[c]	33	40	64	53

Source: Adapted from Sharp and Hawk (1977).

[a] mean of nine values

[b] mean of six values

[c] mean of three values

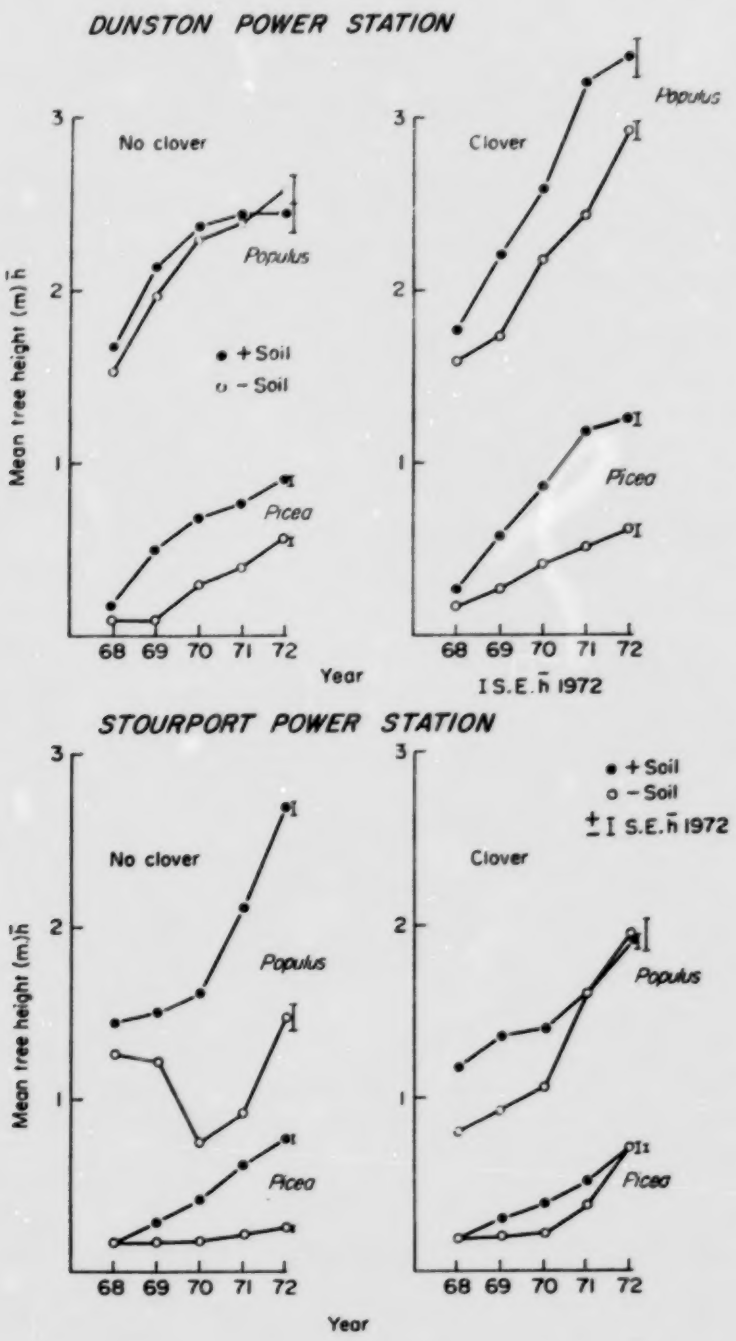

Figure 39.1. Annual height growth of Picea sitchensis and Populus robusta at two British power stations in response to soil and clover.

Source: Hodgson and Buckley (1975)

Table 39.6. Effect of mulch on second and seventh season survival (%) of four species planted into a coastal sand dune in Delaware.

Species	Second Season		Seventh Season	
	Mulch	No Mulch	Mulch	No Mulch
Japanese black pine	78[a]	77	83	70
Rugosa rose	51	71	12	49
Bayberry	43	12	43	11
Bristly locust	63	35	25	20

Source: Adapted from Sharp and Hawk (1977).

[a] Values are means of three treatments.

was species related. Second season survival of M. pennsylvanica and Robinia fertilis was higher in mulched plots, while Rosa survival was lower and Pinus thunbergii was not affected at all. This trend was maintained until the seventh growing season.

A third experiment compared mulch versus no mulch treatments for spring and fall plantings of Pinus thunbergii, Rosa rugosa, Myrica pennsylvanica, and Prunus maritima. First season survival was improved by mulch for the spring plantings of P. thunbergii (90% versus 75%), P. maritima (100% versus 88%), and M. pennsylvanica (46% versus 29%). By the sixth growing season only Pinus showed the improved effects of the mulch (88% versus 65%).

In a fourth experiment, several species were planted in spring with and without mulch. Survival was improved for most species when mulched (Table 39.7).

From these studies Sharp and Hawk (1977) noted the importance of season- and species-related responses to amendments.

39.2.2 Mountains and Foothills Region

Draves and Berg (1979) have reported on several studies performed at the Colowyo Mine, Colorado (elevation = 2256 m) during the years 1975 to 1978.

In the first experiment, eight shrub species were transplanted as bare-root or container stock in the spring with or without a straw mulch.

After one growing season overall survival was quite low (<30%). Mulching appeared to have produced a negative effect on survival of the shrubs, especially the containerized stock (Table 39.8). The authors suggested that this may be due to the mulch intercepting and retaining precipitation at the expense of the transplants during a drier than usual year.

In the second study, five different management practices were evaluated with and without a grass/legume understory (Table 39.9). The seed-bed was prepared by chiselling the soil on the contour, leaving ridges approximately 15 cm apart and 8 cm high. Seed was hand broadcast

Table 39.7. Survival (%) of eight species planted onto a sand dune in Delaware as affected by a mulch.

Common Name	Scientific Name	Survival	
		Mulch	No Mulch
Flameleaf sumac	*Rhus copallina*	34	2
Waymyrtle	*Myrica cerifera*	57	25
Bayberry	*Myrica pensylvanica*	79	29
Mugo pine	*Pinus mugo* var. *mughus*	55	25
Chokecherry	*Prunus virginiana*	79	50
Beach plum	*Prunus maritima*	75	71
Oleaster	*Eleagnus umbellata*	59	58
Bearberry	*Arctostaphylos uva - ursi*	50	8

Source: Adapted from Sharp and Hawk (1977).

Table 39.8. Effects of mulch on shrub seedling survival, Colowyo Mine, Colorado.

Species	Total No. of Transplants	% Survival	
		Control	Mulched
BARE ROOT STOCK			
Chokecherry	52	12	18
Oak	50	0	19
Serviceberry	118	0	0
CONTAINERIZED STOCK			
Bitterbrush	53	29	0
Mountain mahogany	48	69	31
Serviceberry	48	50	25
Snowberry	50	65	75
Oregon grape	8	0	0
Common juniper	5	50	0
Oak	48	0	0
OVERALL SURVIVAL PER TREATMENT		24%	17%

Source: Adapted from Draves and Berg (1979).

Table 39.9. Effects of mulching on the establishment of four seeded shrub species, Colowyo Mine, Colorado.

Shrubs	Number of shrub seedlings per 50 m^2									
	Seeding Only		Mulched		Fertilized		Mulched & Fertilized		Rolled & Mulched	
	1976	1978	1976	1978	1976	1978	1976	1978	1976	1978
Seeded Shrubs										
Bitterbrush	39	11	94	21	39	11	89	26	83	24
Serviceberry	44	14	117	37	28	19	150	29	289	65
Snowberry	ND	11	17	17	ND	ND	ND	5	ND	13
Oak	5	ND	5	ND	ND	1	5	2	ND	1
Seeded Total	88	36	233	75	67	31	244	62	372	103
Volunteer Shrubs										
Big sage	55	37	189	97	83	62	116	84	261	149

Source: Adapted from Draves and Berg (1979)

onto this surface on 21 October 1975. Freeze-thaw action and moisture sloughed soil into the furrows, covering the seed.

The shrub seed mixture and rates were: Amelanchier alnifolia, 1.1 kg/ha; Symphoricarpos sp., 0.6 kg/ha; Purshia tridentata, 0.6 kg/ha; and Quercus gambelli, 1 acorn/1.86 m^2. The grass and forb seed mixture consisted of: Agropyron trachycaulum, 11.2 kg/ha; Bromus inermis, 11.2 kg/ha; Penstemon spp., 2.2 kg/ha; and Hedysarum borealis var. utahensis, 2.2 kg/ha.

The nine treatments were replicated three times. The mulching consisted of spreading Medicage hay at a rate of 4.5 t/ha and then securing it with cotton netting. Plots were rolled prior to and after shrub seeding, and fertilized in the spring.

Data on the total number of shrubs per 50 m^2 are given for the first and third growing seasons (Table 39.9). Mulching had no significant effect on shrub establishment where shrubs were seeded with a grass/legume mix; however, mulching had a pronounced effect on plots where only shrubs were seeded. The combined treatment of rolling and mulching produced the best cover of seeded species but it also encouraged invasion of Artemisia tridentata. Mulching appeared to account for most of the increase in shrub density on the mulched and fertilized plots.

A third study, seeded two years later, assessed the same nine management practices using a different seed mix consisting of: Amelanchier alnifolia, 2.2 kg/ha; Symphoricarpos, 1.1 kg/ha; Purshia tridentata, 1.1 kg/ha; Quercus gambelli, 1 acorn/9.3 m^2; Prunus virginiana, 2.2 kg/ha; and Rosa sp., 1.1 kg/ha. The grass and forb seed mixture consisted of: Agropyron trachycaulum, 5.6 kg/ha; Bromus marginatus, 5.6 kg/ha; Penstemon spp., 2.2 kg/ha; Penstemon lentus, 1.1 kg/ha; and Hedysarum borealis var. utahensis, 2.2 kg/ha. The shrub seeding rate was increased over the previous study with the expectation that more shrubs might be established. The seed-bed was prepared by rototilling the area immediately prior to seeding. Seed was hand broadcast on 28 September 1977 and was allowed to be covered naturally.

Compared to the previous study, establishment rates were low. In this experiment, the addition of a mulch improved only the establishment of Amelanchier alnifolia on the plots seeded with a grass/legume cover. The rolled and mulched treatment was, again, the best in terms of shrub establishment.

In the fourth study Draves and Berg (1979) compared the effectiveness of mulches that were created from the pre-disturbance vegetation (Artemisia tridentata and Amelanchier alnifolia) and two commercial mulches (wood chips and straw). The Amelanchier and Artemisia were chipped into pieces, varying in size from 15 cm in length and 2.5 cm in diameter to fine shreds of bark. The five treatments in this study were:

1. Chipped Amelanchier at a rate of 29 t/ha (55% ground cover).
2. Chipped Artemisia at a rate of 10 t/ha (40% ground cover).
3. Wood shavings at the rate of 45 t/ha (100% ground cover).
4. Straw at a rate of 10 t/ha (100% ground cover). The straw was crimped into the soil with a hand crimper.
5. No mulch (control).

Seed-bed preparation consisted of discing down the existing vegetation, rototilling, and chiselling to leave furrows approximately 18 cm apart and 8 cm deep. The seed was hand broadcast on 28 September 1976 and covered with soil by freeze-thaw action and moisture sloughing.

The seed mix and rates included: A. alnifolia, 1.1 kg/ha; Purshia tridentata, 0.56 kg/ha; Prunus virginiana, 13.4 kg/ha; Bromus marginatus, 5.6 kg/ha; Agropyron trachycaulum, 5.6 kg/ha; Hedysarum borealis var. utahensis, 2.2 kg/ha; and Penstemon spp., 1.1 kg/ha.

Data on the number of shrubs per 50 m^2 were taken for the first and second growing seasons. Shrub counts were extremely low for all treatments, probably due to very low precipitation in the first growing season. Amelanchier alnifolia was again the only seeded species to benefit from mulching. Improvement occurred only on the chipped

A. alnifolia mulch. The chipped Artemisia mulch enhanced the invasion of Artemisia tridentata significantly. Total live cover (seeded shrubs plus grass/legume mix) was lowest for the wood shavings mulch. Draves and Berg (1979) found that spreading wood shavings at 45 t/ha resulted in a layer 5.1 cm thick which apparently acted as a physical barrier to the emergence of small-seeded species.

In the fifth study, four management practices were assessed for erosion control:

1. Shrubs only. Shrub seeded at the rate of: Amelanchier alnifolia, 1.1 kg/ha; Symphoricarpos sp., 0.6 kg/ha; Purshia tridentata; and Quercus gambelli, 1 acorn/1.80 m^2 (three replications).
2. Shrubs, grasses, and forbs. Shrubs seeded at the above rate plus Agropyron trachycaulum, 11.2 kg/ha; Bromus inermis, 11.2 kg/ha; Penstemon spp., 2.2 kg/ha; and Hedysarum borealis var. utahensis, 2.2 kg/ha (three replications).
3. Shrubs, grasses, and forbs--mulched and fertilized. Shrubs, grasses, and forbs were seeded at the above rates and the plots mulched with 4.5 t/ha Medicago sativa. The plots were fertilized with 67.2 kg/ha N in the spring of 1976 (three replications).
4. Shrubs, grasses, and forbs--mulched. Seeding was done at the above rates and the plots mulched with 4.5 t/ha Medicago (one replication).

Ten plots, 3.3 m by 22.3 m, were constructed on an 18% north-facing slope. The seed-bed was prepared by raking to break up the surface crust. On 01 October 1975 seed was hand broadcast onto the plots and lightly raked to cover the seed. Medicago hay, used on plots receiving a mulch treatment, was spread by hand at a rate of 4.5 t/ha and held in place with cotton netting.

Data on the number of shrubs per 50 m^2 are given for the first and third growing seasons. Mulching again resulted in increased

Amelanchier alnifolia establishment (Table 39.10) and volunteer establishment by Artemisia tridenata.

39.2.3 Plains Region

Sindelar et al. (1974) planted caliper-size bare-root trees (3.2 cm diameter, 1.8 to 3.0 m tall) onto shaped and topsoiled coal spoils at the Rosebud Mine, Montana. Ten of each of the following species were used: (1) Populus alba, (2) Populus sargentii, (3) Salix pentandra, (4) Salix alba var. vitellina, (5) Fraxinus pennsylvanica, (6) Elaeagnus angustifolia, and (7) Ulmus pumila. Trees were planted in May and half were "mulched" using a black plastic apron around the base to warm the soil and retard moisture loss by evaporation. The other half were left as controls.

All trees survived the first growing season, and were subjectively evaluated as to growth, vigour, and condition at the end of June. Elaegnus angustifolia was rated as good, S. alba as poor, and all others as fair. Survival was assessed in August of the second growing season. The plastic apron mulch appeared to enhance growth and survival of some species (Table 39.11). Unfortunately, mule deer damaged a number of the trees making interpretation of survival data difficult.

The authors noted that E. angustifolia and S. alba var. vitellina exhibited the best condition and survival rate in the two-year study period, especially when mulched with the black plastic aprons.

Fifth season survival data from the same study were collected by DePuit, Coenenberg and Willmuth (1978). At this time the plants established with the plastic apron treatment had higher survival rates than the controls (Table 39.11). At the end of the fifth season, E. angustifolia, Fraxinus pennsylvanica, and Ulmus pumila had the highest survival rate. Salix alba var. vitellina survival had dropped considerably from the second season.

They also reported on an experiment assessing the impact of two mulches on survival of Pinus ponderosa planted on coal spoils at Colstrip, Montana. Seedlings, as 2+0 bare-root stock, were planted by hand on a series of three soil treatments in April 1974. These

Table 39.10. Number of shrub seedlings per 50 m^2, 3.4 m x 22.3 m runoff plots, Colowyo Mine, Colorado.

	Management Practices							
			Shrubs, Grasses, & Forbs Seeded					
	Shrubs seeded only		Seeding only		Mulched		Mulched & Fertilized	
	1976	1978	1976	1978	1976	1978	1976	1978
SHRUBS								
Seeded shrubs								
Bitterbrush	9	9	1	1	6	2	3	1
Serviceberry	4	2	3	3	11	9	11	2
Snowberry	ND[a]	ND	ND	ND	ND	ND	ND	1
Volunteer Shrubs								
Big sage	3	9	3	8	87	227	17	20

Source: Adapted from Draves and Berg (1979).

[a] ND = No data

Table 39.11. Survival and vigour of 70 deciduous trees on mine spoils at Rosebud Mine, Colstrip, Montana, as affected by use of a plastic apron mulch.

Species	Second Season				Fifth Season			
	Apron		Control		Apron		Control	
	Surv. (%)	Vigour[a]	Surv. (%)	Vigour	Surv. (%)	Vigour	Surv. (%)	Vigour
Green ash	100	P	100	P	100	G	40	F
Russian olive	100	G	100	G	100	F	100	F
Siberian elm	100	F	80	F	100	F	80	F
Silver poplar	80	P	20	P	40	F	20	F
Cottonwood	100	F	40	P	40	F	0	-
Golden willow	100	G	80	P	40	F	20	F
Laurel willow	40	P	40	P	0	-	0	-

Source: Adapted from Sindelar et al. (1974) and DePuit, Coenenberg and Willmuth (1978).

[a] Vigour evaluated using a qualitative rating system: P = poor, F = fair, G = good.

treatments included a scoria (porcellanite) application 15 to 30 cm in depth, a straw mulch of about 15 700 kg/ha, and a bare ground (not topsoiled) control. Twenty-four plots were laid out in a completely randomized design with twelve replications in the control treatment and six each in the scoria and straw mulch treatments.

Each plot contained 49 trees spaced at 2.4 m intervals. A small amount of soil from a nearby native P. ponderosa site was placed in each hole before planting the seedlings. The purpose of this procedure was to re-establish mycorrhizal populations and thereby increase chances of seedling survival. All soil treatments were fertilized as its addition had been noted to stimulate P. ponderosa seedlings.

Plant mortality was evaluated in July of the first growing season, June of the second, and August of the third by noting the colour and adhesiveness (persistence) of the needles. In the first season, the straw mulch was the most effective in preventing early seedling mortality (8%). Plants with the scoria mulch had the greatest mortality rate. By the second season the mortality rate was much higher in all treatments but still lowest in the straw mulched plots (45%). Mortality was virtually 100% on all treatments by the end of the third season.

DePuit, Coenenberg and Willmuth (1978) concluded that the use of bare-root stock in such rocky soil, even with a mulch, was not a suitable reclamation technique. They felt the prime causes of planting failure in this study were occasional non-vertical ("J") terminal root orientation in too shallow holes and excessive competition from other vegetation. The straw mulch reduced seedling mortality substantially in the first two years but lost its effectiveness by the third season. The scoria treatment, used to simulate the rocky soils common under P. ponderosa, had the greatest first season mortality but was better than control plots by the second season.

Aldon and Springfield (1975, 1977) performed several small experiments to evaluate the moisture conserving abilities of several mulches for early establishment of Atriplex canescens and Caragana arborescens on coal spoils in New Mexico (elevation = 1554 to 1707 m).

In the first experiment, ground paraffin and black polyethylene were placed around A. canescens transplants to provide an effective rainfall collecting area of 0.37 m^2. Paraffin was applied at a rate of 3.7 kg/m^2. The paraffin melts into the soil at 53.9°C and forms a surface coating which prevents infiltration and directs water to the base of the seedling. Growth of the transplants reflected the increase in available moisture. The plants, only 5.1 cm tall at the start of the experiment, had the following heights 75 days later: untreated, 15.2 cm; paraffin, 22.9 cm; and polyethylene, 35.6 cm.

In a simultaneous study, 50 C. arborescens plants were planted on mine spoils near Gallup, New Mexico. Seedlings were planted in shallow basins, and paraffin and polyethylene were applied as in the above study. No precipitation fell for the first two weeks after planting and was low thereafter. All plants survived, but those treated with ground paraffin showed better vigour. One year later the plants surrounded by the polyethylene were almost twice as large as the controls (Table 39.12).

In addition to paraffin, a silicone spray emulsion was tested on spoil material to evaluate its potential for repelling water and thus concentrating runoff. Both strength and water repellence of the silicone crusts were influenced by concentration and rate of application. Increasing either concentration or application rate improved overall performance of the crust. If the crust became fractured, however, water repellence was greatly reduced. Although all the wax treatments produced a soft and easily disturbed crust, they gave better water repellence than the silicone, whether the wax was disturbed or not.

Aldon and Springfield (1975, 1977) also examined the effects of a straw mulch and a white portland cement slurry mulch on the germination and establishment of A. canescens. Seeds were sown in March when temperatures were optimum. Mulches were applied alongside the seeded rows. By the end of August, 83% of the straw mulched seedlings were alive, followed by the cement mulch (80%) and the controls (71%).

Table 39.12. Growth of transplanted Siberian peashrub as affected by two mulching treatments, on coal spoils near Gallup, New Mexico.

Treatment	Height (cm)	Diameter (cm)	Size Index (ht x diam)
No treatment	22.6	7.9	178.5
Ground paraffin	24.6	11.4	280.4
Polyethylene	40.6	15.7	637.4

Source: Aldon and Springfield (1975).

In coal spoils in west-central New Mexico, Scholl and Aldon (1979) examined the effects of spoil shaping and two types of surface sealing materials on the establishment of Atriplex canescens, Elaeagnus angustifolia, Caragana arborescens, and Forestiera neomexicana.

The spoil material was a moderately saline (EC = 5 mmhos, SAR = 10), mildly alkaline (pH = 7.8) clay derived from poorly consolidated shale and sandstone. The material had been mined two years before and was graded nearly level just before shaping began in August 1974. Water harvesting furrows, 4 and 7 m in width, were selected to determine water harvesting effects on plant growth. The above widths correspond to 3:1 and 6:1 ratios of water collecting to plant growing areas. The furrow sides were graded to a 6% slope, and both sizes had plant growing areas 1 m wide. Furrows, 24 m long, were formed with a road grader and check dammed at 8 m intervals to obtain three replications. The treatments included both the harvesting area comparision, two types of surface sealing materials, and shaped and unshaped checks. The sealing materials used were ground paraffin and a silicone water repellent with a latex soil binder (Dow Corning XZ8-5079). Ground paraffin was hand scattered on the harvesting surface at 1 kg/m^2. Under dry summer conditions on the coal spoil, the paraffin melted and penetrated several millimetres in five days. The silicone and latex material (6% emulsion in water) was sprayed on the shaped spoil at a rate of 3 L/m^2. The surface was hot and dry for several days after application, allowing the latex to cure completely. The latex emulsion penetrated an average of 1 cm and formed a soft but water repellent crust.

Four- to six-month-old shrubs were transplanted from pots in August. Data on plant height and crown diameter were collected one and two years after planting. Second year data indicated no improvement in plant growth due to the soil sealers; in fact, the silicone treatment reduced growth (Table 39.13). The shaping treatments were much more important in determining plant growth. The authors noted that the failure of the soil sealers may have been due to the natural sealing tendency of the sodic, clay spoils.

Table 39.13. Plant and soil moisture response to water harvesting on coal mine spoil in west-central New Mexico.

Species	Shaping treatments			Sealing of shaped surface		
	6:1	3:1	None	Paraffin	None	Silicone
Height (cm)						
Fourwing saltbush	83 a	77 a	63 b	89 c	88 c	62 d
Russian olive	72 a	64 a	31 b	74 c	81 c	50 d
Siberian peashrub	32 a	30 a	16 b	34 c	34 c	25 d
New Mexico olive	17 a	15 a	10 a	18 c	17 c	13 c
Crown diameter (cm)						
Fourwing saltbush	102 a	90 a	67 a	104 c	107 c	77 c

Source: Adapted from Scholl and Aldon (1979).
Note: Values in rows with similar letters are not significantly different (P = 0.5).

39.2.4 Other Geographic Regions

Carpenter, Graves and Kruspe (1978a,b) experimented with several mulches for establishing trees. They noted that area mulching is expensive and that mulching of individual trees, especially when they are widely spaced, may be just as effective at reduced cost. One important question when using this method is the amount of soil surface surrounding each seedling which must be covered to significantly raise survival. They set up an experiment with several mulching materials to attempt to answer this question.

A randomized block experiment with three replications, containing four tree species, six individual tree mulches, and a control was established on new surface mine spoil in the vicinity of Colmar, Kentucky in March 1977. Seventy 1+0 seedlings of Platanus occidentalis, Alnus glutinosa, Pinus taeda, and P. virginiana were planted at a spacing of 1.8 x 1.8 m. Immediately after planting, 10 randomly located trees of each species within a block were mulched with the following materials: 0.9 x 0.9 m clear polyethylene plastic; 0.9 x 0.9 m fibreglass mat; 15.2 cm fibreglass disc; 30.5 cm fibreglass disc; latex rubber spray; and bark. The 10 remaining trees of each species within a block were not mulched and served as a control.

The clear polyethylene plastic was 1.5 mm thick and was weighted down with loose spoil at the edges to keep it in place. The fibreglass mat and discs consisted of 0.6 cm borosilicate glass fibre which permitted moisture to penetrate. The edges of these were also weighted. The latex spray consisted of a 1:5 rubbery polymer emulsion-water mixture which was sprayed in a 0.3 m diameter circle around each seedling. The bark treatment consisted of unprocessed sawmill residue which contained both large pieces of bark and sawdust. Approximately 0.012 m^3 was applied in a circular fashion around the base of each seedling.

The study site was a gentle slope of south-east aspect. The spoil had a bulk density of approximately 2.0 with a pH of 6.0. After the trees were planted, the study area was first hydroseeded with a

mixture of Festuca rubra cv. Kentucky 31 and Melitotus officinalis, and then fertilized.

Survival, height, diameter, and vigour observations were made soon after planting and again at the end of the growing season. Both the polyethylene plastic and the fiberglass mat treatments resulted in a significant increase in survival (Table 39.14). The latex spray, which acts as an anti-transpirant, ranked third, but was not significantly different from the control. Survival for the trees with the bark mulch was significantly lower than the control. Vigour followed the same pattern as survival. Seedling height after one growing season was significantly greater on the polyethylene sheets treatments.

Carpenter, Graves and Kruspe (1978a) felt, that while expensive, this treatment significantly increases survival, vigour, and growth of tree species. In addition it can be used on steep and rough terrain which would be inaccesible to equipment.

Albers, Howard and Carpenter (1978) examined the effects of several mulches on the survival and leaf water potential of Alnus glutinosa seedlings planted onto coal spoils in Kentucky. The plots were established on previously revegetated spoil consisting of, on the average, 27 percent sand, 59 percent silt, and 15 percent clay. The bulk density was approximately 2.0 with the spoil appearing more dense on the flat aspect than on the north and south aspects. Plots were scalped of established vegetation. Those designed to assess competition were reseeded with Festuca rubra cv. Kentucky 31, Trifolium pratense, and Mellilotus officinalis. Lolium perenne was also found as a volunteer species on the competition plots.

The experiment used a replicated block design. Three blocks were located on north, south, and flat aspect positions. Each consisted of three replicates containing eight 4.6 by 4.6 m plots. All plots were planted with 80 1+0 A. glutinosa seedlings, requiring 5760 seedlings for all 72 plots.

Each plot in each row received one of eight treatments, selected at random (Table 39.15). Seedlings were planted in March 1977 and assessed for survival in April 1978 after the seedlings had leafed

Table 39.14. Effect of individual tree mulches on the survival, vigour, and height of four species of tree seedlings after one growing season, on coal spoils near Colmar, Kentucky.

Treatment	Survival[a]		Percentage Vigour[b]		Height in cm	
	Mean	Range	Mean	Range	Mean	Range
Clear Plastic (0.9 x 0.9 m)	55.0 a	(10-90)	3.5 a	(2.0-4.0)	98.9 a	(54.1-119.9)
Fiberglass Mat (0.9 x 0.9 m)	53.5 a	(20-80)	3.2 ab	(3.0-3.6)	82.8b	(47.0-122.4)
Latex Spray	42.3 b	(10-80)	3.2 ab	(2.8-4.0)	90.2ab	(51.8-144.8)
30.5 cm Fiberglass Disc	40.0 b	(10-80)	3.0 ab	(2.5-3.3)	72.1bc	(52.1-125.7)
Control	36.2 b	(0-70)	2.5 bc	(1.0-3.2)	59.7c	(44.4- 99.1)
15.2 cm Fiberglass Disc	33.3 b	(0-70)	2.8 ab	(1.0-3.4)	77.2bc	(48.3-116.8)
Bark	27.5 c	(0-80)	2.3 bc	(1.0-3.0)	63.0c	(45.2-116.8)
All[c] Prob F=	0.0001		0.0001		0.0032	

Source: Adapted from Carpenter, Graves and Kruspe (1978a).
Note: Means followed by the same letter are not statistically different at the 0.05 level of probability by Duncan's Multiple Range Test.
[a] Survival percentages were transformed by the arc-sine P method for statistical analysis.
[b] Vigour is a visual rating based on the condition of the main stem and foliage: 4=good-vigorous, healthy appearance; 3=fair-some chlorosis, minor foliage dieback; 2=poor-severe stem and foliage dieback; 1=dead.
[c] One-way analysis of variance for treatment.

Table 39.15. Survival of Alnus glutinosa seedlings as affected by mulch, on surface mine spoil in eastern Kentucky, after one growing season.

Treatment	Average percent survival			
	North	South	Flat	Mean
5 cm bark	49 a	12 a	45 a	35 a
5 cm bark with ground cover	0 b	0 b	4 c	1 c
Hydromulch-latex[a]	39 a	2 b	14 b	18 b
Hydromulch-latex with ground cover	1 b	5 ab	1 c	2 c
Latex	35 a	1 b	5 bc	14 bc
Latex with ground cover	0 b	4 b	0 c	1 c
Control	27 ab	0 b	1 c	9 bc
Control with ground cover	1 b	0 b	0 c	0 c

Source: Adapted from Albers, Howard and Carpenter (1978).
Note: Figures within a column followed by the same letter not significantly different at P = 0.05 using Duncan's Multiple Range Test.
[a] Hydromulch applied @ 7.5lbs/225ft^2 with overspray of latex @ 0.5 gal/225 ft^2 diluted with 3 gal of water.

out. Plots mulched with 5 cm of bark had the greatest survival rate (Table 39.15). Survival of trees on plots without a grass/legume cover was consistently higher than on plots with a seeded ground cover.

The authors concluded that a bark mulch could significantly improve the early survival of trees planted on coal spoils. While this is technically correct, survival was quite low and varied with aspect.

Ringe and Wittwer (1978) examined the effects of 2.5 and 5 cm of bark mulch on the survival of Alnus glutinosa, Pinus virginiana, and Quercus rubra planted into coal spoils in eastern Kentucky. Trees were planted with a 1.8 x 1.8 m spacing, 36 trees per plot.

With the exception of Q. rubra, seedling survival was significantly greater under 2.5 cm of bark than where no mulch was applied (Table 39.16). The survival of P. virginiana was further increased under 5 cm of mulch. The authors noted that the trees appeared to be more vigourous and healthy in the mulch treatments.

Wittwer, Graves and Carpenter (1979) examined the effects of a bark mulch and fertilizer on growth of four tree species seeded into coal spoils near Middlesboro, Kentucky. The experiment consisted of three blocks, utilizing a split-plot design. Each block was divided into four, equal size, soil amelioration treatment subplots, separated with a 1.2 m buffer zone. These treatment subplots were further divided into four tree species subplots, 5.4 m x 5.4 m with one of the following species randomly assigned to each plot: Quercus rubra, Q. prinus, Q. palustris or Pinus virginiana. Within each species subplot, 100 seed-spots were located on a 0.6 x 0.6 m spacing. Seeds of the appropriate species were placed in a planting hole and covered to a depth equal to the diameter of the seed. For Q. rubra and Q. palustris, two acorns were placed in each planting hole. Seeding rates for P. virginiana consisted of six to ten seeds per spot. For Q. prinus, a species exhibiting no winter dormancy, a single acorn with a normally developing radicle was placed in each planting hole.

Soil amelioration treatments are shown in Table 39.17. Mulching consisted of broadcast spreading shredded bark and wood waste to a depth of 2.5 cm, after the seeds were planted. The bark and wood

Table 39.16. Survival of three tree seedlings under different bark mulch levels (no herbaceous cover) in eastern Kentucky.

Mulch (cm)	Mean Survival (%)		
	Alder	Pine	Oak
0	41 a	37 a	54 a
2.5	85 b	55 b	77 a
5.0	75 b	71 c	63 a

Source: Adapted from Ringe and Wittwer (1978).
Note: Values within a column followed by the same letter are not significantly different at P = 0.05 using a t-test.

Table 39.17. First year stocking of direct seeded trees by species and treatment, on coal spoils near Middlesboro, Kentucky.

Treatment	Stocking percent[a]				
	Northern Red Oak	Chestnut Oak	Pin Oak	Virginia Pine	Mean
Control	52	31	27	14	31 a
Bark mulch	71	36	29	41	44 ab
Fertilizer	44	35	31	40	38 ab
Bark mulch and fertilizer	60	32	48	70	53 b
Mean	57 a	34 b	34 b	41 b	

Source: Adapted from Wittwer, Graves and Carpenter (1979).
Note: Means in a column or row followed by the same letter are not significantly different at the 0.05 level.
[a] Percentage of seed spots with at least one surviving seedling when observed in mid-October.

waste was obtained from a sawmill processing a variety of native hardwood species, primarily oaks and hickories. Seeding and treatment applications were completed during mid-March.

Data on first season stocking and seedling height were collected in mid-October. Mulching increased mean stocking density over the controls but only the mulch plus fertilizer combination significantly improved stocking (Table 39.17). Quercus rubra and P. virginiana seemed to derive the greatest benefit from mulching. The authors noted that Q. rubra under mulch, and Q. rubra and P. virginiana under the mulch, plus fertilizer treatment attained the 55% stocking level suggested for direct seeded Pinus in the south-eastern United States.

Mulch significantly improved height growth (mean of all species, Table 39.18). Quercus rubra had the greatest increase in growth with the mulch treatment. The mulch plus fertilizer treatment was significantly better than either mulch or fertilizer alone. Although Pinus virginiana was the smallest of all species at the end of the year, it showed the greatest height response to the fertilizer and mulch treatment.

The authors concluded that Quercus and P. virginiana can be established by direct seeding techniques, especially when spoils are mulched and fertilized. They noted that this is especially important for Quercus as conventional bare-root seedlings often fail due to difficulties with the prominent taproot system.

39.3 SUMMARY

Topsoiling has been used very little as an amendment for tree and shrub planting and results have not been consistent.

Mulching has been studied extensively. Straw and hay mulches have been used but with minimum success. In some instances straw has had a negative effect through interception of precipitation in dry years. Use of these materials may lead to invasion of weed species.

Bark, wood wastes, and chipped materials have received considerable attention, particularly in the eastern United States.

Table 39.18. First year height growth of direct-seeded trees by species and treatment, on coal spoils near Middlesboro, Kentucky.

Treatment	Total height, cm				
	Northern Red Oak	Chestnut Oak	Pin Oak	Virginia Pine	Mean
Control	6.2	7.4	8.5	2.0	6.0 a
Bark mulch	9.0	9.2	10.5	2.3	7.8 b
Fertilizer	10.1	7.3	10.8	1.9	7.5 b
Bark mulch and Fertilizer	13.4	11.1	15.2	5.3	11.2 c
Mean	9.7 a	8.8 a	11.2 b	2.9 c	

Source: Adapted from Wittwer, Graves and Carpenter (1979).
Note: Means in a column or row followed by the same letter are not significantly different at the 0.05 level.

Success has been quite variable. Wood shavings have been found to restrict seedling emergence of some species, while others (e.g., Amelanchier alnifolia) seem to benefit from wood mulch. Mulching with bark in combination with fertilization is often beneficial. Use of chipped weedy species may lead to invasion of that species (e.g., Artemisia tridentata).

Area mulching is expensive and therefore individual trees are often treated when planted. Soil sealants have been used quite frequently to direct water to the base of the planted seedling. Polyethylene in particular, and paraffin have proved quite successful in this respect. Survival and height growth have been improved. Fibreglass matting has also been used effectively. Other materials such as silicone, latex rubber spray, bark/sawdust mix, and fibreglass discs have been less effective and in some cases reduced survival and growth.

Combination soils shaping (e.g., furrows) and soil sealant treatments have indicated that the shaping treatment provides by far the greatest benefit.

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40. FERTILIZATION FOR ESTABLISHMENT OF TREES AND SHRUBS

40.1 NORTH-EAST (OIL SANDS) REGION

There were no published examples of fertilizer research on woody species in the Oil Sands region. The following study is included because the sandy substrate is similar to that of the Syncrude and Suncor tailings.

Sharp and Hawk (1977) tested the effects of two fertilizers on survival and growth of several species planted as one- or two-year-old bare-root seedlings onto a coastal dune near Lewes, Delaware. Plots were mulched in fall or spring, planted in fall or spring, and fertilized with 30 g of magnesium ammonium phosphate (MagAmp), 30 g of 10-6-4, or left unfertilized. The MagAmp was placed in the bottom of the planting hole while the 10-6-4 was broadcast around each shrub in the spring of the second growing season. In general, the greatest effects were those of the mulching and planting times. The interaction between those parameters and the fertilizers was also important. The reader is encouraged to read the report for further details.

In the first experiment, Rosa rugosa and Myrica pennsylvanica were planted in fall and spring. By the end of the second growing season survival of both species was better on the unfertilized plots (Table 40.1) and remained so to the end of the ninth growing season. The 10-6-4 fertilizer gave a slight improvement in survival over MagAmp. The M. pennsylvanica plants fertilized with MagAmp were larger than either the control or 10-6-4 fertilized plants.

In the second experiment, twenty-five seedlings of each species were planted in the spring with and without a mulch. The same fertilizers were assessed. The species were: (1) R. rugosa, (2) M. pennsylvanica, (3) Pinus thunbergii, and (4) Robinia fertilis. Survival data were taken for the second and seventh growing seasons. Plant size was measured in the seventh growing season.

Response to the fertilizers varied with species (Table 40.2). Survival of the Pinus and Robinia was improved by MagAmp fertilizer and

Table 40.1. Effects of fertilization on survival (%) and growth of two shrub species planted on a coastal dune in Delaware.

Season	Rose			Bayberry		
	Survival (%)		Growth (cm)	Survival (%)		Growth (cm)
	2	9	9	2	9	9
MagAmp	30(16-68)	24(4-68)	33x40	42(4-68)	42(4-68)	91x88
10-6-4	39(16-72)	28(12-56)	33x41	55(45-80)	53(42-80)	91x76
Control	56(38-76)	39(20-68)	43x44	64(48-76)	62(40-76)	84x81

Source: Adapted from Sharp and Hawk (1977).

[a] Growth measured as mean height x mean width.

[b] Arithmetic mean of 5 planting and mulching treatments; range in brackets.

Table 40.2. Effects of fertilization on survival (%) and growth (cm) for four species planted on a coastal sand dune in Delaware.

Fertilizer	Pine	Rose	Bayberry	Locust	Mean
Second Season Survival (%)[a]					
MagAmp	94	58	26	66	61
10-6-4	62[c]	66	29[c]	24	45
None	77	58	26	56	54
Seventh Season Survival (%)[a]					
MagAmp	88	22	24	36	43
10-6-4	67[c]	40	30[c]	12	37
None	74	30	26	20	45
Seventh Season Growth (cm)[a,b]					
MagAmp	130 x 99	12 x 15	84 x 76	39 x 31	66 x 55
10-6-4	128 x 97	39 x 39	69 x 69	39 x 31	69 x 59
None	122 x 91	33 x 56	54 x 54	39 x 23	62 x 56

Source: Adapted from Sharp and Hawk (1977).

[a] Values are arithmetic means of two mulching treatments.

[b] Growth measured as mean height x mean width.

[c] No explanation given for the increased percent survival from second to seventh growing seasons.

depressed by the 10-6-4. The fertilized Pinus were slightly larger than the controls.

MagAmp had no effect on the survival of Rosa or M. pennsylvanica. The 10-6-4 application slightly improved survival of both species. The Rosa plants fertilized with MagAmp were stunted as compared to the controls; the 10-6-4 plants had slightly better growth than control plants. The M. pennsylvanica plants, on the other hand, were larger when fertilized with MagAmp than the 10-6-4 fertilized plants or the controls.

In the third experiment, several species were planted in the spring into plots which were mulched in fall or spring and given either MagAmp or 10-6-4 fertilizer. Data on percent survival and growth were taken in the eighth growing season.

Results were species related and the effects of fertilizers were modified by the mulching effects (Table 40.3). For example, Prunus maritima had slightly higher mean survival with the application of MagAmp (75%) than with 10-6-4 (70%). Upon closer examination, however, the interaction with mulching time was very important; MagAmp improved survival for the fall mulched plants while 10-6-4 improved the spring mulched plants. The reverse was true for Prunus virginiana.

Sharp and Hawk (1977) noted that effects of the two fertilizers were highly dependent upon species and planting and mulching time.

40.2 MOUNTAINS AND FOOTHILLS REGION

Draves and Berg (1979) transplanted Amelanchier alnifolia shrubs onto north-facing 18% slopes on coal spoils at the Colowyo Mine in Colorado. Shrubs were planted in holes 61 cm in diameter and 51 cm deep with or without 0.45 kg of MgAmp slow-release fertilizer.

Survival was high but the plants fertilized with MgAmp showed a marked reduction in flowering compared with those not fertilized (6% versus 73% respectively).

Table 40.3. Effects of fertilizers on the survival (%) and growth (cm) of nine species planted onto a coastal dune in Delaware.

Species	Survival (%) MagAmp M[a]	MagAmp F	MagAmp S	10-6-4 M[a]	10-6-4 F	10-6-4 S	Growth (cm)[b] MagAmp	Growth (cm)[b] 10-6-4
Prunus maritima	75	92	58	70	58	83	36 x 32	53 x 46
Prunus virginiana	75	83	67	66	100	33	75 x 75	83 x 83
Rhus copallina	17	34	0	19	34	4	44 x 29[c]	53 x 30
Cystisus scoparius	17	25	8	0	0	0	90 x 90	ND[d]
Myrica cerifera	41	50	33	42	67	17	112 x 82	99 x 76
Myrica pensylvanica	46	75	17	58	83	33	119 x 127	106 x 106
Eleagnus umbellata	66	75	58	50	42	58	60 x 45	53 x 46
Pinus mugo mughus	37	42	33	42	67	17	45 x 67	46 x 61
Polygonum cuspidatum compacta	33	50	17	29	17	42	11 x 15	8 x 15

Source: Adapted from Sharp and Hawk (1977).

[a] Arithmetic mean of fall (F) and spring (S) mulching treatments.

[b] Growth is measured as mean height x mean width of spring and fall mulch treatments.

[c] Growth measured for one treatment only.

[d] No values.

Bauer, Berg and Gould (1978) reported on a study in which bare-root shrubs (Rhus trilobata, Rosa sp., and Caragana arborescens) were planted in silty clay spoils with 60% shale fragments, generated by limestone mining in north-eastern Colorado. Concentrated superphosphate, at a rate of 20 g of P per shrub, was applied to one half of the shrubs in two slits 15 cm deep on two sides of the plant.

There was no statistical significance in shrub survival between fertilized (60%) and non-fertilized plots (70%). The P fertilization, however, significantly improved seedling vigour (Table 40.4), especially for Caragana.

40.3 PLAINS REGION

Howard, Schuman and Rauzi (1977) collected random samples of topsoil and newly exposed overburden from two coal mines and a uranium mine in Wyoming. The materials were ground and mixed prior to greenhouse experiments. The pretreatment pH and EC_e of the topsoil and overburden were presented in Chapter 33. The species and soil mixtures used were also discussed previously (Chapter 39). Fertilizer treatments included an untreated control and 67 kg/ha of N or P alone or in equal combination, for each of 45 pots in each fertilizer treatment. Plant height data were collected to evaluate growth.

The addition of N or N plus P significantly improved mean height growth of the combined shrub species on all soils (Table 40.5). The P and combined N and P treatment did not improve growth over the N alone.

There were some significant species - fertilizer interactions. Ceratoides lanata responded significantly to N fertilization (Table 40.6). The combination N and P fertilizer and P alone had no effect. Atriplex canescens responded significantly to the combined N and P treatment. There were no significant fertilizer effects on the growth of the other three species.

From these studies the authors noted, that as a group, the shrubs responded to N fertilization; however, certain species

Table 40.4. Shrub vigour ratings, made visually, as influenced by spot P fertilization of limestone spoils in Colorado.

Species	Percent					
	Non-fertilized			P-fertilized[a]		
	Good	Fair	Poor	Good	Fair	Poor
Rhus trilobata	51	31	18	71	21	8
Rosa sp.	66	26	8	72	15	13
Caragana arborescens	18	26	54	39	42	9

Source: Reproduced from Bauer, Berg and Gould (1978), Reclamation of Drastically Disturbed Lands, 1978, pages 451-466 by permission of the American Society of Agronomy. Crop Science Society of America and Soil Science Society of America.

[a] 20 g per shrub.

Table 40.5. Mean height of combined shrub species grown on topsoil, overburden and mixture from three Wyoming mine sites under four fertilizer treatments.

Mine and treatment	Height (cm)[a]			
	Control	67 kg N/ha	67 kg N/ha + 67 kg P/ha	67 kg P/ha
Seminoe No. 1	10.1	16.5	16.4	11.4
Wyodak	10.5	16.5	16.7	11.7
Utah International	9.2	16.2	16.6	11.2
Mean	9.9 b	16.4 a	16.6 a	11.6 b

Source: Adapted from Howard, Schuman and Rauzi (1977).

Note: Means followed by same letters do not differ at the 5% level of probability of Fisher's method.

[a] Values are single plot arithmetic means calculated from five reps. and three soil mixtures.

Table 40.6. Mean height (cm) of five shrub species under four fertilizer treatments from three Wyoming mines.

Treatments (kg/ha)	Winter-fat[a]	Salt-tree	Rabbit-brush	Fourwing saltbush	Silver sage
Control	6.0 b	16.1 a	17.4 a	5.9 b	4.1 a
67 N	18.5 a	19.9 a	25.6 a	13.4 ab	4.6 a
67 N + 67 P	12.0 ab	22.9 a	24.1 a	16.2 a	7.8 a
67 P	5.9 b	23.0 a	16.5 a	7.7 ab	3.9 a

Source: Adapted from Howard, Schuman and Rauzi (1977).
Note: Column means followed by same letter do not differ at the 5% level of probability by Fisher's method.
[a] Single plot means of five replicates and three mine sites.

(Halimodendron halodendron, Chrysothamnus nauseous and Artemesia cana) were capable of good growth without any fertilization at all.

Aldon and Springfield (1973, 1977) and Aldon, Springfield and Scholl (1976) examined the effects of fertilization on survival of Atriplex canescens and Sporobolus airoides planted on coal spoils in New Mexico. In two early greenhouse experiments, additions of 896 kg/ha or 1792 kg/ha of 10-5-5 fertilizer did not improve seedling emergence of A. canescens but did improve their height and yield. The higher fertilization rate did not improve growth over the low rate.

In a later experiment, composite spoil samples from the Navajo Mine, west of Farmington, New Mexico, were placed in 1 L round pots (10 cm diameter, 12 cm tall). Each pot was filled with 1.2 kg of the spoil material which had been sieved through a 1.3 cm mesh. Fertilizer treatments included three levels of nitrogen and phosphorus in all combinations. Nitrogen was applied as ammonium sulfate (21-0-0) and phosphorus as treble superphosphate (0-45-0). Levels of application were as follows:

1. N_0 or P_0 = no fertilizer
2. N_1 or P_1 (lower level) = 89.7 kg/ha
3. N_2 or P_2 (higher level) = 179.4 kg/ha

Fertilizer was applied on 31 May the time of seeding (T), as a mixture with the top 4 cm of spoil in the pot. Fertilizer applied one or two months after seeding (T_2, T_3) was spread uniformly over the surface of the spoil. Moisture content of the pots was held at approximately field capacity for the 90-day duration of the experiment. Temperature means were 17.7°C (night) and 31.9°C (day).

Thirty seeds of one species were planted in each pot at the start of the experiment. Sporobolus airoides seed was covered with about 0.5 cm of spoil in the experiment and Atriplex canescens with about 1.0 cm of spoil.

Emergence of the two species was not affected by fertilizer treatment. Application date of the fertilizer did not influence height of Sporobolus. Delaying application until two months after seeding resulted in shorter plants of A. canescens. The highest level of P, in

combination with either level of N, tended to produce the tallest plants of Atriplex canescens, whereas the highest level of N, in combination with either level of P, produced the tallest plants of S. airoides.

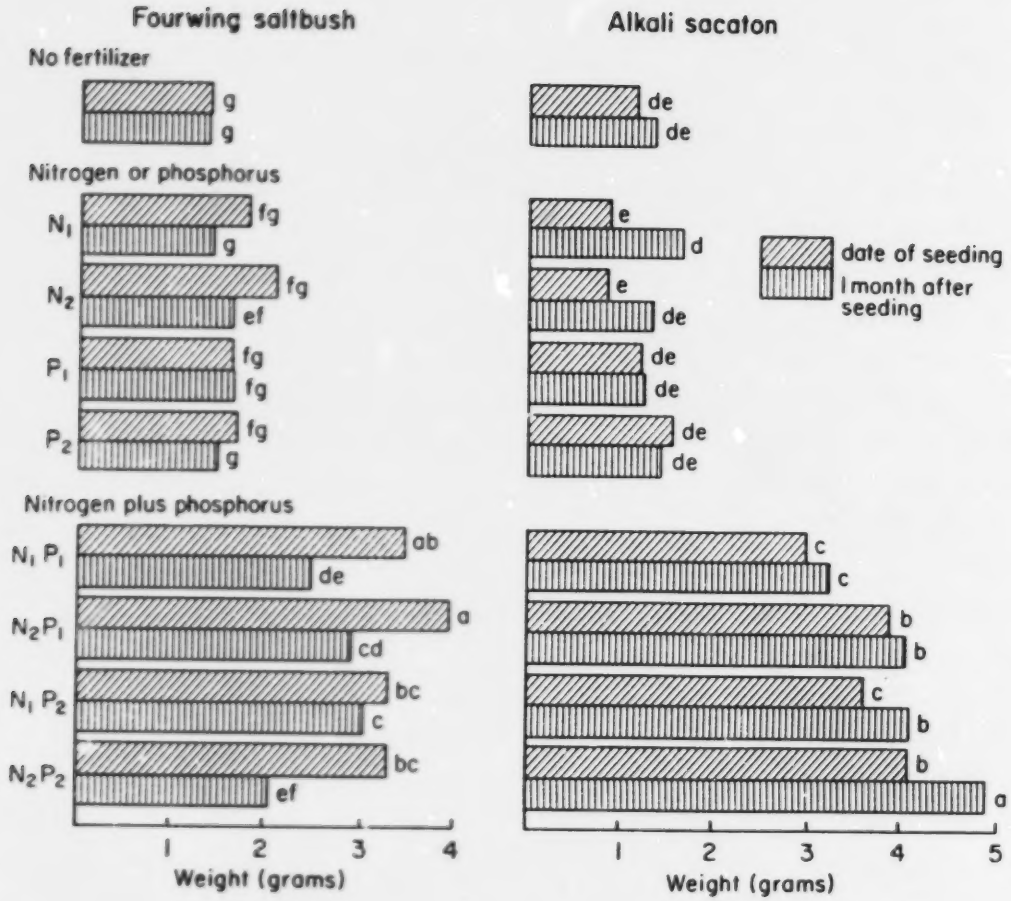
Plant yields were significantly affected by application date and by levels of N and P. Sporobolus airoides was able to utilize N and P applied 30 days after seeding, whereas A. canescens appeared to respond more slowly. Neither species improved its yield when fertilized with N or P separately; however, yields significantly improved when a combination of N and P were applied (Figure 40.1). Sporobolus airoides responded best to the high level of N and P applied one month after seeding, Atriplex canescens to the N_2P_1 treatment applied at seeding time. However there was no significant difference between N_1P_1 and N_2P_2.

Aldon, Springfield and Scholl (1976) concluded that the lower fertilizer levels are adequate for both species, but that S. airoides showed its best yield from a delayed fertilizer application.

40.4 OTHER GEOGRAPHIC REGIONS

In early reclamation trials on acid coal spoils near Kemmerer, Wyoming, May et al. (1971) found that fertilization with nitrogen, in the form of ammonium nitrate (at 37 or 74 kg/ha), did not significantly affect tree survival or growth after five growing seasons. Seedlings of Caragana arborescens, Juniperus virginiana, Elaeagnus angustifolia, Ulmus pumila, and Rhus trilobata were planted on four slope locations: (1) on the flat top of a high spoil bank, (2) the flat top of a lower spoil bank, (3) the upper eastern and north-eastern facing slopes of a spoil bank, and (4) the lower eastern and south-eastern slopes of a spoil bank.

First year survival of E. angustifolia was increased by fertilization only on Site 4. All other sites had reduced survival rates when fertilized. Survival of U. pumila increased on Site 1 with fertilization at both levels and at Site 4 with 74 kg/ha. All other sites experienced similar or reduced survival rates with fertilization.



N_1 or P_1 = 89.7 kg/ha

N_2 or P_2 = 179.4 kg/ha

Figure 40.1. Response of fourwing saltbush and alkali sacaton to N and P fertilization at two different times. Bars labeled with the same letter are not significantly different at the 0.05 level.

Source: Aldon, Springfield and Scholl (1976:3)

C. arborescens survival increased on Site 1 with 74 kg/ha N and on Site 3 with 37 kg/ha N.

Ringe and Wittwer (1978) examined the effects of fertilizer applications on survival of Alnus glutinosa, Pinus virginiana, and Quercus rubra planted in coal spoils in eastern Kentucky. Diammonium phosphate (18-46-0) was applied at 280 kg/ha and 560 kg/ha onto plots with a 2.5 cm layer of bark mulch. One set of plots was not fertilized. Forty-nine trees were planted in each plot.

Survival rates ranged from 59% to 85% and were not significantly affected by fertilizer rate. The trees did appear to be more vigourous and healthy than those not fertilized.

Wittwer, Graves and Carpenter (1979) examined the effects of a fertilizer and a bark mulch on growth of four tree species seeded into coal spoils near Middlesboro, Kentucky. The experimental methods have been previously described (Chapter 39.2).

The fertilizer treatment consisted of placing a 9 g fertilizer tablet (18% N, 8% P_2O_5, 3% K_2O, 1% Mg) approximately 2 cm away from each seed spot at the time of planting. Seeding and treatment applications were completed during mid-March.

Data on first season stocking and seedling height were collected in mid-October. Fertilization increased mean stocking density over the controls but only the mulch plus fertilizer combination significantly improved stocking (Table 39.17). Quercus rubra and Pinus virginiana seemed to derive the greatest benefit from fertilization. The authors noted that Q. rubra under mulch, and Q. rubra and Pinus under the mulch plus fertilizer treatment attained the 55% stocking level suggested for direct seeded Pinus in the south-eastern United States.

Fertilizer significantly improved mean height growth of all species (Table 39.18). Quercus rubra had the greatest increase in growth with the fertilizer treatment. The mulch plus fertilizer treatment was significantly better than either mulch or fertilizer alone.

Bengtson, Mays and Allen (1973) tested the effects of fertilization and grass cover on establishment and growth of Pinus taeda seeded onto acid coal spoils in north-eastern Alabama. Recently mined spoils were graded to a gentle contour (less than 5% slope) and plots set up in early April. Three spoil plots were graded in February and one in April. The spoil pH range was 5.0 to 5.7. Available P, K, and Mg levels were 12.3 to 78.4, 71.7 to 143.4, and 114.2 kg/ha, respectively.

Within each block, plots were assigned at random among the 25 treatments which consisted of all combinations of the following variables:

1. Grass species seeded -- None, Festuca arundinaeca cv. K 31; Cynodon dactylon
2. Year of grass seeding -- 1969, 1970;
3. Fertilizer rate -- 0, 56, 112 (kg N/ha) applied as APP;
4. Fertilization timing -- All in 1969, half in 1969 and half in 1970.

Suitably treated, 60-day-stratified Pinus taeda seed was broadcast by hand over all plots at a rate equivalent to 1.4 kg of seed (about 22 000 seeds) per hectare. Grass seed was sown over those plots scheduled for seeding in 1969, Festuca at 28 kg and Cynodon at 16.8 kg per hectare. Ammonium polyphosphate (APP) was broadcast at prescribed rates to those plots, according to the treatment schedule, and grass was seeded on those plots scheduled for seeding in 1970.

Data on survival, growth, and stocking were taken in the fall of 1969 and spring of 1970 and 1971. Where Pinus was seeded alone, fertilizers had no significant effect on first season survival. Seedling growth in the first season was mainly a function of fertilization; unfertilized seedlings produced only a few purplish primary needles and achieved minimal height growth after germination. Where grasses were seeded with the Pinus, fertilization increased grass

survival and production, while reducing Pinus survival and growth through competition.

During the first winter, mortality due to frost-heaving was highest for unfertilized seedlings. Tree growth in the second season was improved with the addition of fertilizers; however, the timing of the application had little or no effect on growth.

Minimal Pinus mortality occurred in the third season, while differences in growth among fertilizer treatments continued to increase (Table 40.7). Stocking was considered satisfactory (55% or better) only on the plots without grasses fertilized at 112 kg/ha in 1969. Adequate stocking occurred in three other plots (44%).

From these studies Bengtson, Mays and Allen (1973) concluded that fertilization affected the growth of Pinus more than its survival where grass cover was not present. Fertilizers increased competition from seeded grasses, thus reducing tree seedling survival.

Zarger et al. (1973) and Bengtson, Mays and Zarger (1971) discussed three experiments which tested the effects of fertilization on survival and growth of Pinus taeda on acid coal spoils in north-eastern Alabama. In the first experiment, thirty-six 0.04 ha plots were set up in March on graded spoil banks which had been planted with 1+0 P. taeda seedlings the year before. Twenty-five trees were tagged in each plot. A factorial design with four replications was used to test three levels of N and P (Table 40.8). The N source was ammonium nitrate while P was supplied as concentrated superphosphate. Fertilizers were broadcast uniformly over the surface.

At the end of the first growing season, five of the eight fertilizer applications had produced height growth significantly greater than that on control plots (Table 40.8). There was no significant effect from N alone or the low P rate alone. Phosphate alone, at the high rate, resulted in a significant height growth increase. Application of both N and P at the low rate (28 kg/ha of each) resulted in significantly larger trees than without treatment. Maximum growth was attained with combination NP treatments where either N or P, or

Table 40.7. Effects of fertilization and grass seeding on third season survival and height growth of loblolly pine seeded onto coal spoils in northeastern Alabama.

Grass species	Year grass seeded	Fertilizer rate (total) kg N/ha	Timing and rate of N as APP 1969	Timing and rate of N as APP 1970	Pine seedling survival[a]	Pine seedling height, m	Milacre Stocking, %
None	--	0	--	--	2.0	0.28	6
		56	56	--	7.0	0.63	19
		56	28	28	5.7	0.42	12
		112	112	--	15.2	0.84	69
		112	56	56	10.2	0.83	44
Fescue	1969	0	--	--	3.2	0.20	12
		56	56	--	1.7	0.51	6
		56	28	28	3.7	0.27	12
		112	112	--	1.2	0.61	6
		112	56	56	5.5	0.82	31
Fescue	1970	0	--	--	4.2	0.24	31
		56	56	--	8.7	0.63	37
		56	28	28	16.0	0.66	44
		112	112	--	9.2	0.85	31
		112	56	56	12.5	0.76	31
Bermuda	1969	0	--	--	2.2	0.24	6
		56	56	--	0.2	--	0
		56	28	28	0.2	--	0
		112	112	--	0	--	0
		112	56	56	0	--	0
Bermuda	1970	0	--	--	4.0	0.45	12
		56	56	--	8.7	0.54	37
		56	28	28	3.7	0.63	25
		112	112	--	10.2	0.74	44
		112	56	56	7.7	1.02	31
		LSD (95% level)			2.7	0.70	

Source: Adapted from Bengtson, Mays and Allen (1973).
[a] Number of trees per 6.1 x 6.1 m plots.

Table 40.8. Effect of N and P fertilization on height growth (m) of 1-0 loblolly pine seedlings outplanted one year on acid coal spoils in northeastern Alabama.

N kg/ha	P in kg/ha 0	28	112	Mean
0	0.24	0.37	0.40[a]	0.34
28	0.31	0.46[a]	0.55[a]	0.43[a]
112	0.24	0.55[a]	0.55[a]	0.46[a]
Mean	0.27	0.46[a]	0.49[a]	ND

Source: Adapted from Zarger et al. (1973).

[a] Significantly different from control at the 1% level.

both, were applied at the 112 kg/ha rate; survival was excellent, with only one seedling dying.

In the second experiment, diammonium phosphate (DAP) was applied in March to graded spoil banks which had been seeded to Pinus taeda the previous spring. A factorial design was set up to test the effects of 0, 134.4, and 537.6 kg/ha of DAP supplying 0, 28, and 112 kg/ha N and 0, 31.4, and 125.4 kg/ha P.

The higher DAP rate resulted in a significant increase in tree height growth over controls after one year. Seedlings in plots with no fertilizer grew 9.1 cm. In contrast growth of seedlings treated with 134.4 kg DAP was 15 cm, increasing to 30.5 cm with the 537.6 kg application of DAP. Overall seedling survival was excellent and all control plants lived.

In the third experiment, DAP was applied at 134.4 and 537.6 kg/ha in July or September to plots seeded in April to P. taeda (1.12 kg/ha) and P. virginiana (0.11 kg/ha). A control plot remained unfertilized. Survival and growth measurements were made at the end of the growing season.

The best growth and survival occurred on plots fertilized at the high level in July (Table 40.9). Seedlings fertilized in September showed little or no height growth response but their colour and vigour were somewhat better than the control plants. Zarger et al. (1973) noted that root response to fertilization, especially in the September fertilized plots, exceeded that of the tops. In addition, fertilized plants survived the winter much better than unfertilized plants (56% versus 17%).

The authors concluded that broadcast fertilization using nitrogen and phosphorous improved vigour and growth rates of Pinus transplanted onto acid coal spoils in north-eastern Alabama. Fertilization did not, however, appear to be essential to plant establishment. On the other hand, fertilization with N and P appeared mandatory when direct seeding Pinus. The seeds germinated without fertilization but did not develop sufficiently strong root systems to

Table 40.9. Height growth and survival of pine seeded on acid coal spoil in northeastern Alabama as influenced by application of diammonium phosphate (DAP).

Treatment date	Fertilizer rate in kg/ha			First year height	First year survival
	DAP	Equiv. N	Equiv.P	cm	%
Control	0	ND	ND	3.66	17
July	134.5	28.0	31.4	4.27	44
July	538.1	112.1	125.6	5.49[a]	56[a]
September	134.5	28.0	31.4	3.66	34
September	538.1	112.1	125.6	4.27	51

Source: Adapted from Zarger et al. (1973).

[a] Significant at 5% level.

resist frost heaving in the winter. Fertilization at seeding produced plants with strong root systems which grew well and survived the winter.

Berry (1979) tested two sizes of Agriform Forest Starter Tablets and three levels of sewage sludge as fertilizers in the Tennessee Copper Basin. The study area was subsoiled using a large crawler-type tractor with two ripping shanks which produced furrows 2.4 m apart and 90 cm deep. Oven dried sewage sludge was shredded to give a particle size of 1 cm^3.

Pinus taeda seedlings were planted by hand in March using a planting bar. The fertilizer tablets or sludge were placed in holes 8 cm from the seedlings and covered with loose soil. Each plot contained 27 seedlings, planted in a single row, 1.2 m apart. Data on seedling diameter were taken two weeks after planting, and in the dormant periods for three years.

Growth of the unfertilized seedlings was poor over the three growing seasons. The fertilizer and sewage treatment effects are shown in Figure 40.2. There were no significant differences in percent survival between treatments after three years.

Berry (1979) concluded that slit application of fertilizers is an alternative to broadcast application. He noted that while broadcast fertilizers may result in more biomass production per hectare, slit applications are less expensive, easier to apply to rugged terrain, and less stimulating to growth of competing vegetation. The Agriform fertilizer tablets, in addition to providing the best growth, were the most convenient to use.

Hodgson and Buckley (1975) studied the effects of nitrogen additions on establishment and growth of trees on pulverized fuel ash (PFA) in England. In the first experiment, Populus robusta was grown on PFA with a cover of Melilotus sp. In the fourth growing season, due to cultivation difficulties, the Melilotus was replaced with a 35 g N treatment applied to each tree in March. By the end of the fifth growing season there was a significant positive response to the N treatment (Figure 40.3).

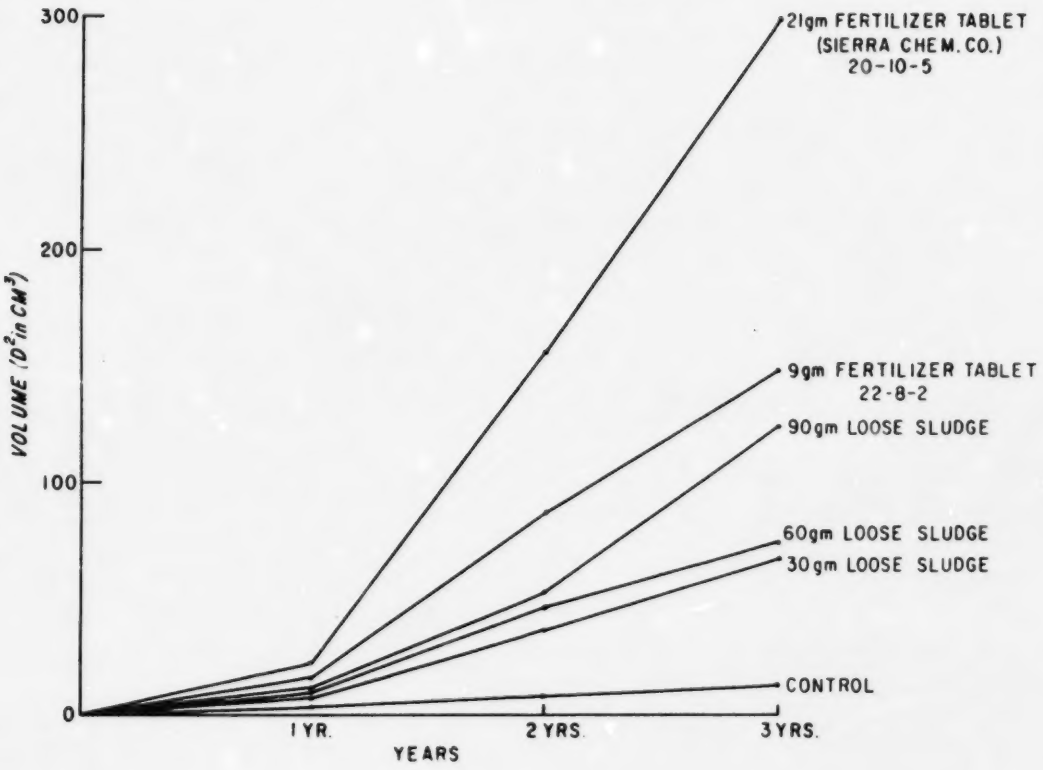


Figure 40.2. Effects of slit applications of dried sewage sludge and Agriform fertilizer tablets on early growth of loblolly pine seedlings at Copper Basin, Tennessee.

Source: Berry (1979)

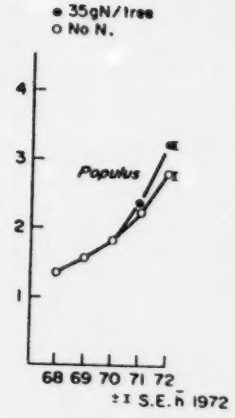


Figure 40.3. Response of Populus robusta to nitrogen at Drakelow Power Station, England.

Source: Hodgson and Buckley (1975:322).

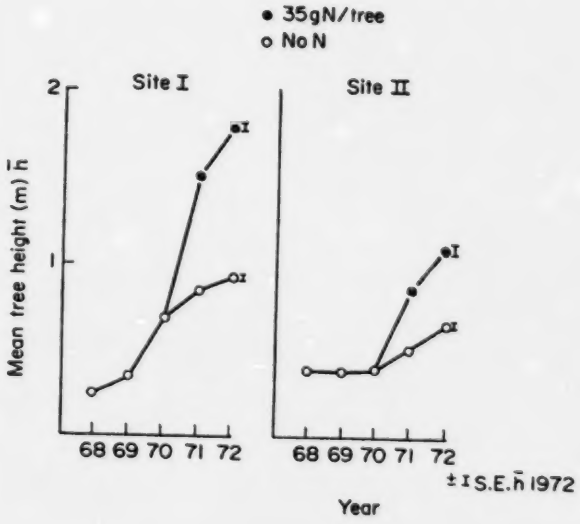


Figure 40.4. Response of Acer pseudoplatanus to nitrogen at two British power station sites.

Source: Hodgson and Buckley (1975:323).

In the second experiment, the response of a fertility demanding species, Acer psuedoplatanus, to nitrogen fertilization was assessed at two sites. Fertilizer was applied in the fourth growing season as 35 g of N per tree. The trees responded favourably by the end of the fourth growing season and continued to show increased growth in the fifth season
(Figure 40.4).

Ledgard (1978) studied the effects of fertilizers on growth of Pinus mugo, Pinus contorta, and Alnus viridis direct seeded on subalpine sites in New Zealand. Growth of P. mugo improved with each addition of P up to 50 kg/ha in a greenhouse experiment (Figure 40.5). Nitrogen significantly increased Pinus growth only when applied with phosphate. Maximum growth rates were produced by 50 kg/ha of N and P.

On bare subsoil where herbaceous cover was introduced, the addition of fertilizers increased competition from the grass/legume cover and decreased survival of Pinus contorta and Alnus viridis (Figure 40.6). The author suggested minimizing initial fertilizer applications in mixed plantings.

40.5 SUMMARY

Fertilizer effects on woody plants vary with species, fertilizer type, other amendments, and fertilization, seeding or planting time. There is no general formula suitable for all situations.

Some species may respond to nitrogen fertilizer, others may require nitrogen in combination with phosphorus. Some species need no fertilization at all.

Fertilizer generally affects vigour, growth, and sometimes survival of woody plants. In some instances, establishment of seeded species has improved significantly with fertilization.

Fertilizers are often quite effective when used in combination with mulches. When woody plants are planted into a grass cover, or grass seeded later, fertilization may stimulate competition sufficiently to reduce survival and growth.

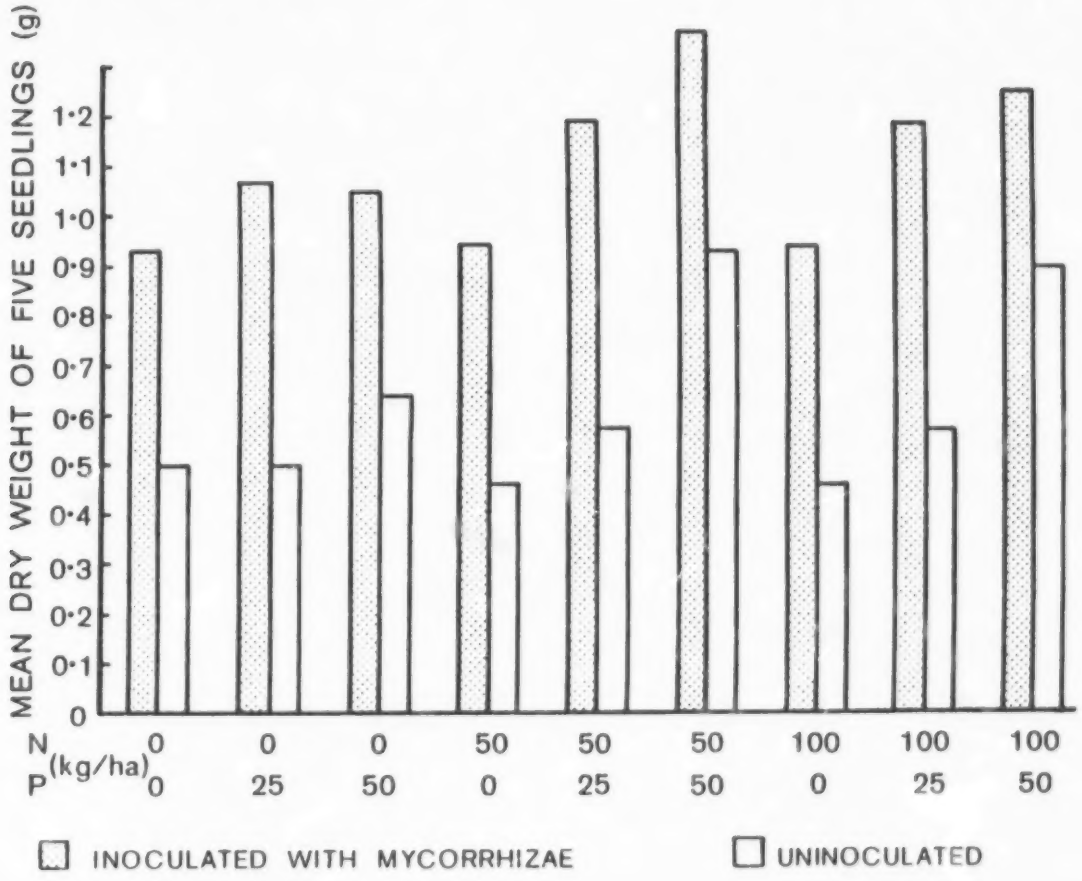


Figure 40.5. Mean dry weights of mycorrhizal and non-mycorrhizal Pinus mugo seedlings grown under nine fertilizer regimes in the greenhouse.

Hedgard (1978)

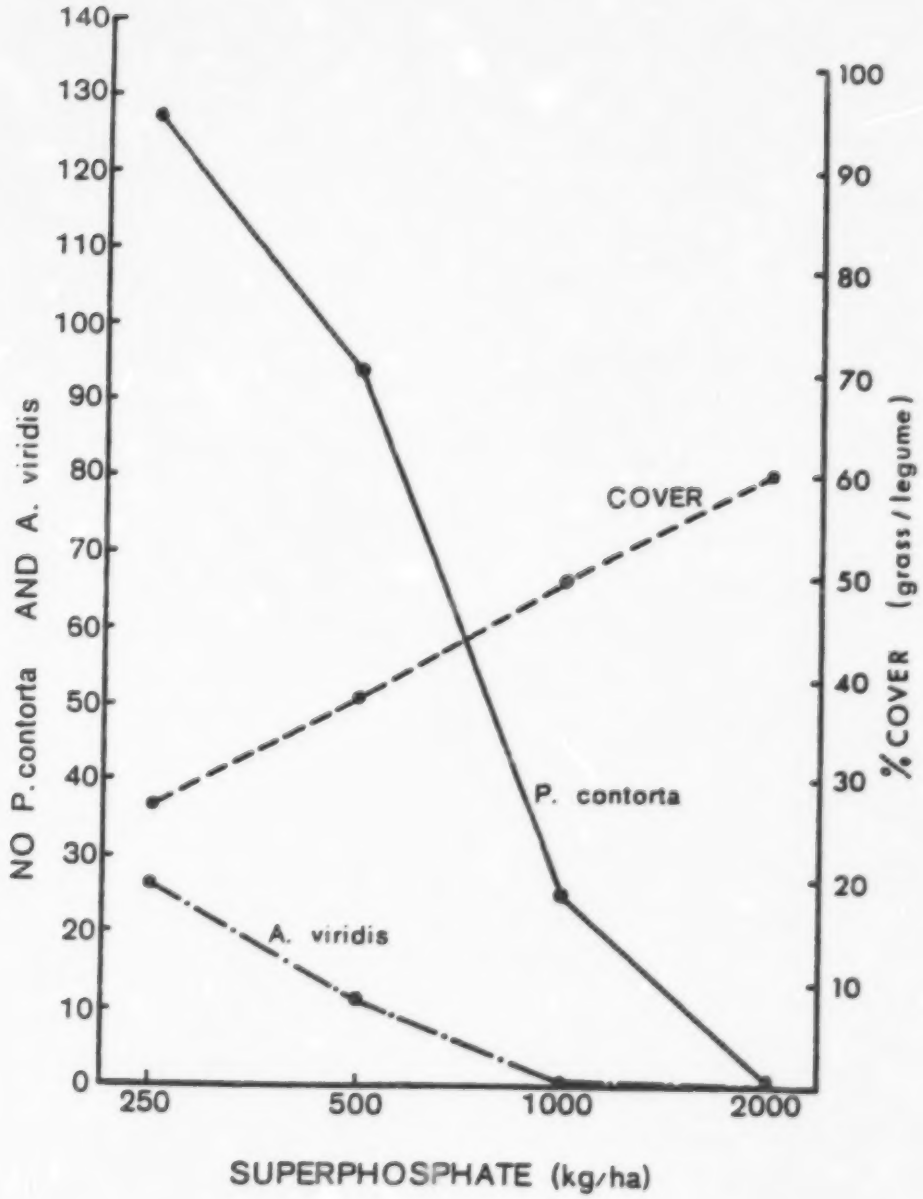


Figure 40.6. Effect of a grass/legume cover on survival of Pinus contorta and Alnus virdis after one winter in Kaweka Range, New Zealand.

Source: Ledgard (1978)

While fertilizers are most often broadcast, pellets may be applied during or after planting. This technique has provided positive results, is less expensive, easy to apply, and does not stimulate competing vegetation.

Fertilization of woody species is probably not warranted except in specific problem situations.

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41. IRRIGATION FOR ESTABLISHMENT OF TREES AND SHRUBS

41.1 MOUNTAINS AND FOOTHILLS REGION

Jensen and Hodder (1979) compared establishment and growth of Atriplex canescens seeded under a sprinkler irrigation system on a 5:1 west-facing slope near Melrose, Montana (elevation = 1600 m). The subsoil consisted of a complex pattern of randomly oriented layers of medium size particles of sand, gravel-sand mixtures, and clay. The area was covered with a 10 cm layer of topsoil salvaged from the adjacent roadway prior to construction. The topsoil was characterized as loamy sand and the subsoil as sandy loam.

The treatments in this study were two levels of irrigation, four types of mulch, and gouging. In July, plots were fertilized and a chisel plow was used to till the study area twice, in opposite diagonal directions. Gouging and mulching treatments were applied where appropriate and A. canescens was broadcast seeded at 2.2 kg/ha. Ten other species were also broadcast seeded.

Following treatment applications, an agricultural type impact head sprinkler irrigation system was installed on the plots. The main line pipe (20.3 cm diameter) with lateral connectors and control valves was positioned along the study area. Four parallel, equally spaced lateral lines were run through all treatment plots. On 24 July, 3.8 cm of water was applied to all treatments at a rate of 0.6 cm/h. Due to variation among sprinkler heads and wind conditions, the total application rate was estimated to have varied ± 10 percent. On 17 August, a similar application of 3.8 cm of water was applied only to the "double application" irrigation treatments.

Data on plant density were taken in November of the first growing season, July of the second, and September of the third. The seed germinated rapidly and established uniform stands of vigourous seedlings, regardless of treatments. Density remained stable for the three-year study period and was not significantly influenced by irrigation treatments.

Orr (1977) tested the effects of irrigation on establishment and growth of shrubs on coal spoils in the Powder River Basin area of Wyoming. In initial studies, bare-root stock planted without additional water into graded spoil was established with moderate success.

From these results it was decided to assess the impact of irrigation on plant establishment. Fraxinus pennsylvanica var. lanceolata, Shepherdia argentea, Juniperus scopulorum, Prunus americana, Caragana arborescens, Pinus ponderosa, and Elaeagnus angustifolia were planted as bare-root stock, 1.8 m apart, with rows 2.4 m apart. One half of the plots were irrigated and one half were left alone.

The irrigation system consisted of a distribution grid of low density, black polyethylene tubing installed on the surface. Filter, regulator, and timer were installed at the well point outlet. Water was metered to individual plants through calibrated emitters designed to deliver 3.8 L/h at 0.7 to 1.05 kg/cm^2 pressure. Water was applied to each plant in one hour, at four-day intervals, from 01 May through 30 September. Under this schedule, irrigated plants received 38 applications of water. If a plant was assumed to have occupied a space half way to adjacent plants in all directions (1.08 m^2), the amount of water applied the entire season was 3.23 cm. If a plant was more realistically assumed to have occupied an area of 0.09 m^2, the depth of water applied was 154.9 cm. On a 0.19 m^2 area, the depth would have amounted to 38.1 cm during the growing season.

The finished spoil on the study site was comprised of 1.4 m or more of the upper 1.5 to 3 m of overburden, end dumped on the travel level and smoothed with blade equipped crawler tractors, thus minimizing compaction. Texture of the emplaced spoil was a surprisingly uniform sandy clay loam with an overall bulk density of 1.55. The saturation moisture content (total pore volume) of 42% was comprised of 23% micro (or retention) pore volume and 19% macro pore volume. Wilting point moisture content was 11%. The spoil was moderately saline, but alkalinity was low (pH 6.6 to 8.6). The sodium adsorption ratio was about 3, indicating low sodium toxicity hazard. In all of these respects the spoils appeared well suited as a planting medium.

For all species except J. scopulorum survival at the end of the third season was greater in the irrigated plots (Table 24.2). The poor survival of Juniperus could not be accounted for. Shepherdia argentea had the largest response to irrigation, although overall survival of the species was still low. Irrigation reduced winter losses (20% versus 43%) as well as summer losses (15% versus 33%). In addition, the irrigated plants appeared to suffer fewer losses from browsing rabbits than the non-irrigated plants. Orr attributed this result to stronger plants in the irrigated plots.

Following these tests a second series of plots was set up to examine the effects of irrigation on bare-root and container grown stock of the same species. By the end of the first growing season there were no effects on plant survival due to irrigation (Table 24.3), however, overall survival was higher for the irrigated plots by the spring of the second growing season. Response of the two conifers to irrigation was positive. Response of the deciduous plants, with the exception of Eleagnus angustifolia, was positive though not as great as the response of the conifers.

Orr also reported on the first year results of a study to assess irrigation, mulching, and fertilization on the establishment and survival of container grown Atriplex canescens, Juniperus scopulorum, Chrysothamnus nauseosus, Artemisia tridentata, and Ceratoides lanata. While the overall results were inconclusive for the first season, the best overall survival occurred in the mulched and irrigated plots and in the irrigated plots. The best over-wintering survival was in the irrigated plots.

From these studies Orr concluded that response to irrigation was generally positive but the magnitude of response was species dependant. Supplemental water tended to reduce over-winter losses more than summer losses.

41.2 PLAINS REGION

Aldon and Springfield (1975, 1977) and Aldon (1975) have reported on the use of irrigation to establish Atriplex canescens on

coal spoil slopes in New Mexico. A drip irrigation system using water storage tanks, plastic pipes, and emitters was set up on an artificially created spillway between coal spoil heaps. A three-month-old plant of A. canascens was placed under each emitter. Plants were watered twice a week from mid-September until the first hard frost (eight waterings at 15.2 L/watering). After the second growing season, 73% of the irrigated plants had survived while significantly fewer unirrigated plants were alive (Table 41.1). The irrigated shrubs were also twice as large as the unirrigated plants.

Aldon and Springfield also tested the effect of watering frequency on growth of A. canescens in the greenhouse. A. canescens was seeded and grown in spoil material for 19 weeks under five different watering regimes totalling from 600 mL to 1500 mL/week and applied through drip emitters. Plant shoot and root lengths were measured and weekly consumption of water was determined from moisture measurements. Applying 400 mL three times a week resulted in excellent growth response. Consumptive water use was significantly different by treatments and by weeks. Use was highly dependent on the total weekly amount of water applied. It also rose steadily for the first four weeks of the test, then levelled off at rates commensurate with the amounts of water applied.

Aldon, Springfield and Sowards (1976) assessed the effects of drip and sprinkler irrigation on establishment and growth of A. canascens at the Navajo Mine, near Farmington, New Mexico. Three spoil amendments were applied in long, narrow strips, 4.6 to 7.6 m wide, across both the sprinkler and drip areas prior to seeding. These amendments included: (1) topsoil, applied 15 to 25 cm deep; (2) bottom ash, applied 15 to 25 cm deep, plowed and disced in; and (3) gypsum, applied at the rate of 17.4 t/ha and disced in. Four strips of each amendment were applied at random intervals on each of the test areas.

In the sprinkler irrigation test, seeds of A. canascens were drill seeded using a Rangeland drill, in two mixes. Other species in the mixes were Sporobolus airoides, Hilaria jamesii, and Oryzopsis hymenoides. Plots were mulched with native hay at 2.7 t/ha and crimped.

Table 41.1. Survival and growth of drip-irrigated Atriplex canescens plants on coal spoils in New Mexico. Measurements taken 22 months after planting.

	Irrigated	Control
Survival (percent)	76.7	50.0
Height (cm)	62.2	44.2
Diameter (cm)	59.7	32.5
Size index (ht. x dia.)	3713.3	1436.5

Source: Adapted from Aldon (1975).

Water was applied through thirty 5 cm diameter lines spaced 12.2 m apart along the long axis of the area. Rainbird full circle sprinkler heads were placed in a diamond pattern at 12.2 m intervals along each line. Each line contained 18 sprinkler heads. Total gross applications ranged from 18.6 cm to 26.4 cm.

Emergence of Atriplex canescens was spotty in this trial, perhaps due to high summer temperatures, so it was difficult to assess the effects of irrigation rates. The best response came from the highest rate of application.

In the drip irrigation test, A. canescens was planted as seeds (50/emitter) or as two-month-old transplants. Individual drip lines were 366 m long with 18 lines in each subplot running parallel and 3 m apart. Application rates are shown in Table 41.2.

Emergence of the seeded Atriplex canescens was low in all treatments, again due perhaps to the hot summer weather; however, emergence was greatest under the highest level of irrigation (Table 41.2). Survival of the transplants was also greatest under the highest level of irrigation. The authors noted that survival was directly related to the amount of water supplied in July and August of the first season. This explains why the lowest survival rate was found under the second lowest rate and not under the lowest total irrigation rate.

From this study the authors concluded that more frequent applications of water produced better stands than less frequent applications. They also noted that responses to watering were species specific.

41.3 SUMMARY

Irrigation usually results in positive growth and survival response of woody plants. However the response is often species related. Irrigation reduces overwinter mortality more than summer mortality.

Table 41.2. Survival of shrubs after one and two growing seasons under drip irrigation, on coal spoils near Farmington, New Mexico.

Water level	Application rates[a] (L/emitter)		Atriplex canescens seeded		Atriplex canescens transplants	
	Total	July & Aug.	1974	1975	1974	1975
D-1	30.8	6.1	9[b]	24	38	43
D-2	28.5	8.7	16	48	55	52
D-3	32.7	17.5	33	51	68	60
D-4	49.8	22.8	46	70	72	68

Source: Adapted from Aldon, Springfield and Sowards (1976).

[a] First value is for June, July and August, second value for July and August only.

[b] Values are means of four surface treatments.

High rates of application give best results but rates are, of course, dependent upon water availability. More frequent applications are most efficient for the same amount of water. Late summer irrigation is most effective. For shrubs and trees, drip irrigation or tube emitters are by far the most practical systems.

Irrigation is expensive and dependent upon water supply. Therefore, it is used only where absolutely necessary. It is doubtful that the treatment is warranted for shrub and tree establishment in Alberta except in very specific situations.

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SECTION XII

PLANT COMMUNITY DEVELOPMENT AND MANAGEMENT

42. NATURAL INVASION AND SUCCESSION

Very little research has been carried out on natural succession on mine spoils or invasion of native species into areas reclaimed with agronomic species. Most studies have simply looked at old mine spoil, untreated and of varying age, and examined species success and diversity in relation to adjacent native lands. While this type of research is valuable, it cannot accurately assess conditions of establishment or relative chance for various species, nor are ideal conditions provided for establishment. Nevertheless, the information is of value in planning research or predicting the probability of transition from exotic to native stands.

Studies in Great Britain have evaluated species characteristics that enhance their ability to establish on spoil. Naturally colonizing plants have large seed, fast growing roots, and the ability to build up humus from leaves (Sheldon 1975). For example, rosette species are good colonizers because they have long tap roots and their leaves provide shade and, thus, reduce soil temperature.

Although birds and mammals were often responsible for tree and shrub establishment, most evidence in North America and abroad tends to support the theory that most natural invaders are windborn. In Great Britain and New Zealand Agrostis tenuis, Dactylis glomerata, Holcus lanatus, Deschampsia flexuosa and D. caespitosa seem to be common early invaders (Richardson 1976; Daft and Nicholson 1974; Dunbar 1974). Early invading woody species are Betula, Salix, Rosa and Rubus which would be wind or animal borne (Richardson 1976; Sheldon 1975). Macyk (1979a,b) found that Salix, Rubus, Populus, Lupinus and Fragaria were common invaders on alpine coal spoils in Alberta. In North Dakota (Wali and Freeman 1973) and Utah (Alvarez, Ludwig and Harper 1974; Table 42.1) grasses and forbs (mainly compositae) are dominant early colonizers.

Richardson, Shenton and Dicker (1971) reported on work in Britain which estimated seed input to a pit heap (south-west slope) to be 2 000 000 seeds per hectare. Greenhouse studies using soil from a comparable heap showed a germination equivalent to 272 000 seeds per hectare (27 seeds per m^2). However, seed density on pit heaps was not

Table 42.1 Prevalent species on mine spoils in Utah on basis of percent frequency times percent presence values. Longevity is noted for each species (A = annual, B = biennial, P = perennial).

Species	F x P	Longevity
Sitanion hystrix (Nutt.) J. G. Smith	2983	P
Cirsium undulatum (Nutt.) Spreng	1603	B
Epilobium paniculatum Nutt.	1318	A
Verbascum thapsus L.	1141	B
Aster sp.	1080	P
Arabis sp.	749	P
Poa pratensis L.	495	P
Erysimum asperum (Nutt.) D.C.	424	B
Taraxacum officinale Weber	325	P
Linaria vulgaris L.	129	P
Tragopogon dubius Scop.	90	B
Agropyron trachycaulum (Link) Malte	81	P
Phleum pratense L.	78	P

Source: Adapted from Alvarez, Ludwig and Harper (1974).

more than one per m^2. The authors attributed much of the attrition to high temperature, drought, wind, and open texture which allows seed to be carried to considerable depth in the heap.

In northern areas (Alaska, Yukon, and Northwest Territories) grasses are dominant native invaders. In many areas of the north, tree and shrub seed sources are simply not present. Agrostis latifolia, Poa lanata, and Calamagrostis canadensis appear to be the best pioneers of totally disturbed moist to dry areas. Luzula confusa, Senecio congestus, Epilobium angustifolium, and Descurlania sopholdes are also common (Hernandez 1972, 1973; Table 42.2).

Unfortunately not all "native" invaders are worthwhile reclamation species. In the Great Plains areas, Kochia scoparia and Salsola kali are early invaders of mine spoil and often comprise over 95% of the vegetative cover (Wali 1980; Howard and Samuel 1979; Lodhi 1979; May et al. 1971). Kochia and Salsola tend to disappear from reclaimed areas after a few seasons. The reason for this was suspected to be exudates from leaves. Leachate of fresh and decaying Salsola leaves was tested to determine the influence on germination and growth of several plants. Leachate of decaying leaves decreased weight of roots and shoots of Kochia and Salsola but not of Melilotus sp. Fresh leaf leachate decreased shoot weight and whole-plant weight of Kochia and shoot weight of Melilotus (Lodhi 1979).

Success of invading species depends upon a number of factors. There is, unfortunately, no surefire method of obtaining natural invasion either as pioneer species or as succession into exotic or agronomic stands; the problem remains a priority area for research.

Generally, heavily seeded and fertilized stands of commercial species form an effective barrier to native invasion in northern and arctic areas (Younkin and Martens 1976; Owen and Van Eyk 1975); natives occurred after two to four years where erosion was not a problem. Most plants of all species occurred on mineral rather than organic soils (Hernandez 1972). However, it has also been stated that stands of introduced species do not appear to present a permanent barrier to natural invasion by natives. Seed and fertilizer application appear to

Table 42.2. Plant species that have shown an ability to invade different areas around the MacKenzie Delta Region, Northwest Territories.

Species	Habitat Moisture	Method[a] of Production	Severity[b] of Disturbance	Inuvik	Reindeer	Tununuk	Tuktoyaktuk
Eriophorum angustifolium	Wet	s	open water	X		X	X
Equisetum spp.			wet mineral	X		X	X
Senecio congestus		s	p & m	X	X	X	X
Eriophorum vaginatum		s	wet mineral	X	X	X	X
Arctophila fulva			wet peat				X
Carex aquatilis		r	wet peat				X
Epilobium angustifolium		s	m & p	X		X	X
Rumex sp.		s	m & p				X
Stellaria monantha		s	m & p	X	X	X	X
Cardamine pratensis		s	m & p	X	X	X	X
Arctagrostis latifolia		s & r	m	X		X	X
Calamagrostis canadensis		s & r	p & m	X		X	X
Poa lanata		s & r	m	X		X	X
Luzula confusa		s & r	m	X		X	X
	Dry						

Source: Hernandez (1972).

a s = seed, r = roots and rhizomes

b p = exposed peat, m = exposed mineral soil.

have a positive effect on native plant invasion where living cover of seeded vasculars remains below 20%. As living cover of seeded vasculars increases above 40% the cover of invading natives decreases (Younkin and Friesen 1976; Younkin and Martens 1976; Hernandez 1973; Dunbar 1971; Table 42.3).

Richardson and Dicker (1972) hydroseeded coal spoils in England to a mix of four tree species along with Festuca rubra and Trifolium repens in a wet mulch of wood, cellulose, and fertilizer. Grass rate was purposely kept low (16.8 kg/ha) to prevent competition with seeded trees. A side effect of the low grass cover and favourable ground conditions created by the mulch was an increase in numbers of invading species and rate of colonization. Species found include Crataegus spp., Rosa spp., Rubus fruticosus, Sorbus aucuparia, Agrostis tenuis, Chamaenerion angustifolium, Dactylis glomerata, Digitalis purpurea, Epilobium parviflorum, Euphrasia officinalis, Hieracium spp., Senecio jacobaea, Taraxacum officinalis, Trifolium pratense, T. procumbens, and Tussilago farfara.

Soil characteristics may determine invasion potential. It has been stated that when 40% of material passes a 2 mm sieve, pioneer species can become established (Richardson 1976). Temperature is also an important factor (see Chapter 9.4.2). Richardson, Shenton and Dicker (1971) noted that southern slopes of English pit heaps were found to be covered with germinating seeds and seedlings of grasses and herbs in autumn and spring. By summer, however, when spoil temperatures reached 57°C, the young plants withered and died. Chemical as well as physical characteristics are also obviously important. Acidity definitely limits invasion success. Cover and species richness were measured on non-acid (25% acid shale and a predominance of fine material), acid (75% acid shale) and intermediate spoil (Glen-Lewin 1979). Acid conditions were very significant in determining vegetation characteristics (Table 42.4).

Mycorrhizal infection has been cited as advantageous or even essential for establishment of natives on mine spoil (Daft, Hacskaylo and Nicholson 1975; Daft and Nicholson 1974). Infection was quite high

Table 42.3. Mean % cover of seeded and invading species on the seed and fertilizer test plots over test section I and II at the Sans Sault Test Site, Northwest Territories, 1971 to 1975.

	[a]	Meadow Foxtail	Creeping Red Fescue	Fowl Bluegrass	Kentucky Bluegrass	Fowler Red Cosmygrass	Sheep Fescue	Meadow Fescue	Canada Bluegrass	Creeping Bentgrass	Streambank Wheatgrass	Redtop	Rough Bluegrass	Slender Wheatgrass	Colonial Bentgrass	Tall Fescue	Intermediate Wheatgrass	Tall Wheatgrass	Crested Wheatgrass
Cover by Seeded Grass - Total	1975	85.4	74.4	73.9	62.4	62.3	56.5	53.9	37.6	34.9	26.5	23.4	14.0	11.6	10.3	7.1	2.8	2.8	2.3
	1973	98.0	70.4	93.3	43.6	66.1	45.8	63.3	46.4	60.2	24.4	38.0	32.8	31.4	9.3	13.1	3.2	2.5	1.8
	1971	63.3	33.0	57.3	22.3	63.5	21.0	27.8	35.3	53.8	12.5	57.5	45.0	32.5	52.0	34.3	23.5	18.5	16.8
Cover by Invading Bryophyte	1975	22.9	13.8	16.9	22.1	25.4	8.9	8.5	25.9	21.4	30.0	29.8	30.0	56.4	48.7	50.2	63.9	59.6	73.2
	1973	1.9	16.2	5.6	8.6	17.6	23.9	24.6	16.6	5.0	35.4	17.4	12.3	37.2	20.8	39.8	32.2	39.8	51.8
	1971	1.6	1.4	2.2	0.2	1.8	0.4	1.4	0.4	0.3	4.9	0.5	0.2	5.3	2.0	2.2	5.9	3.1	10.0
Cover by Native Vasculars	1975	1.0	3.7	5.0	2.1	3.3	2.0	0.9	15.9	6.5	12.3	9.4	13.0	17.3	17.2	14.9	25.9	25.8	25.6
	1973	0	6.8	0.6	0.2	0.1	1.2	0.2	0.7	0.1	6.6	1.2	1.8	2.6	2.0	4.8	0.6	15.0	11.6
	1971	0.1	0.5	0.2	0.2	0	0.2	0.6	0.4	0.4	0.2	0.2	0.6	0.3	0.3	0.2	0.1	0.6	0.2

Source: Adapted from Tomkin and Friesen (1976)

[a] Seeded species are listed (left to right) in order of importance based upon total seeded cover.

Table 42.4. Average cover and species richness for six coal spoil areas of different ages in southeastern Iowa, according to three classes of substrate quality.

Area	Age	Percent Cover			Richness		
		Non-acid	Intermediate	Acid	Non-acid	Intermediate	Acid
Amsberry	5 to 7	49.8	13.3	2.7	23.7	11.0	2.5
Fee	13 to 16	56.0	13.6	3.7	12.0	9.4	3.2
Harrison	17	34.0	17.3	0.5	14.7	7.7	0.8
Wilcox	22 to 23	144.6	67.7	1.3	32.1	21.6	2.7
Watertor	26 to 27	77.8	53.9	10.3	27.8	20.9	7.3
Klein	36 to 38	148.5	42.7	6.0	23.0	15.4	3.9

Source: Glenn-Lewin (1979:572).

(20 to 80%) on the most successful colonizers of coal tips in Great Britain.

Amendments have been used as seed sources for native plants (see Chapter 33 as well). In Alberta, fresh (stockpiled four months) and stored (stockpiled 1½ years) peat was tested. The peat was spread over 1 m of tailings sand and 10 cm of clay to a depth of 15 cm and rototilled to approximately 30 cm depth. In greenhouse tests, stored peat produced 56 plants/m^2 (four species), and fresh peat, 63 plants/m^2 (six species). In the field situation no species cover exceeded 2.5%. After one year it was concluded that amendments would not serve as a significant seedling source; as well, growth was too slow for erosion control. Hathorn, Docksteader and McQueen (1979) spread 5 cm of topsoil over eight potential coal overburden materials in British Columbia. They found that invading species were much more common on the topsoiled plots than on the raw spoil and inferred that seeds had been present in the topsoil. Flyash and gritstone supported the largest population of invaders (36% and 19% of total plot biomass, respectively). Material might be handled differently to promote germination and growth (Fedkenheuer and Heacock 1979). In Colorado and Wyoming (Howard and Samuel 1979), stripped, undisturbed soil laid directly over overburden to a depth of 20 cm produced a very low cover of perennials (4.16 plants/m^2 and 1.77 plants/m^2 on Wyoming and Colorado sites, respectively). Rhizomatous species produced the most plant material. Many species observed in June were gone by September.

As mentioned above, some studies have attempted to trace natural revegetation of disturbed areas by examining spoil of different ages. Of course, conditions for initial establishment are not known for the older materials and would certainly influence subsequent success. However, such studies are of interest with respect to evaluating aggressiveness and longevity of various species.

Spoils of three age classes were examined in Wyoming (May et al. 1971). Precipitation for the area was 24 cm; spoil had high organic and salt content. Four-year-old spoil was loose and erodable, nine-year-old loose but more stable, and 15-year-old stable on level

surfaces and erodable on slopes. On four-year-old spoil, Salsola kali made up 98% of the vegetation and 15 to 20% of total cover. Atriplex nuttallii, Agropyron dasystachum, and Sitanion hystrix were also present. On nine-year-old spoil, plants appeared mainly on areas where snow accumulated. Salsola kali made up 95% of total cover with some Bromus tectorum, Bromus sp., Circium arvense, Elymus cinereus, and Sitanion hystrix. On 15-year-old spoil, S. hystrix made up 90% of cover with Hordeum vulgare and Salsola kali next most important. Total cover was 30 to 35%. Similar studies were carried out in New Mexico on one- to 13-year-old spoil of sandstone origins (Wagner, Martin and Aldon 1978). Precipitation in the area was 38 cm, mainly as rain in July to October. Diversity was found to be much greater on unmined sites; less than 44% of 163 taxa were found on spoil and 34 taxa was the greatest number found on a mined plot. There was a gradual change from a large number of annuals and a few perennials on newly mined sites to fewer annuals and more perennials on older sites. However, after 13 years the mined sites bore little resemblance to unmined sites (Figures 42.1 and 42.2).

Wali (1980) carried out quite a detailed study of invasion and succession on spoil piles in North Dakota. He examined three slope positions at eight compass directions on each of 45-, 30-, 17-, 7- and 1-year-old spoil. Vegetation cover ranged from 25 to 50 percent in the first year following abandonment to 75 to 95% after 45 years. As well, species and species diversity changed with age (Figure 42.3). On topsoiled spoil, Wali stated that regardless of species seeded, the initial vegetation composition was determined by seed in the topsoil (cf. Fedkenheuer and Heacock 1979; Hathorn, Docksteader and McQueen 1979; Howard and Samuel 1979); Kochia was most dominant in the first two years.

Glenn-Lewin (1979) sampled north, east, south and west aspects and ridge and draw locations on 5- to 7-, 13- to 16-, 17-, 22- to 23-, 26- to 27-, and 36- to 38-year-old orphan spoils in Iowa. Spoil was very acid to neutral, eroded, and subject to high surface temperature.

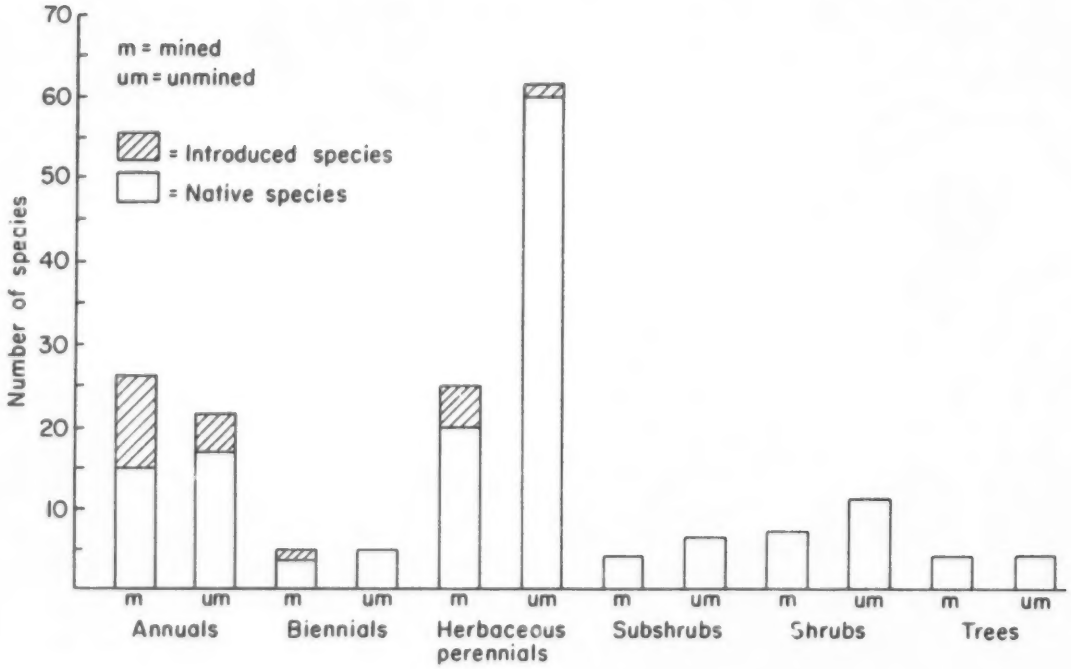

Figure 42.1. Species diversity (numbers) of native and introduced taxa in each life-form category on mined and unmined areas of the McKinley Coal Mine, New Mexico.

Source: Wagner, Martin and Aldon (1978)

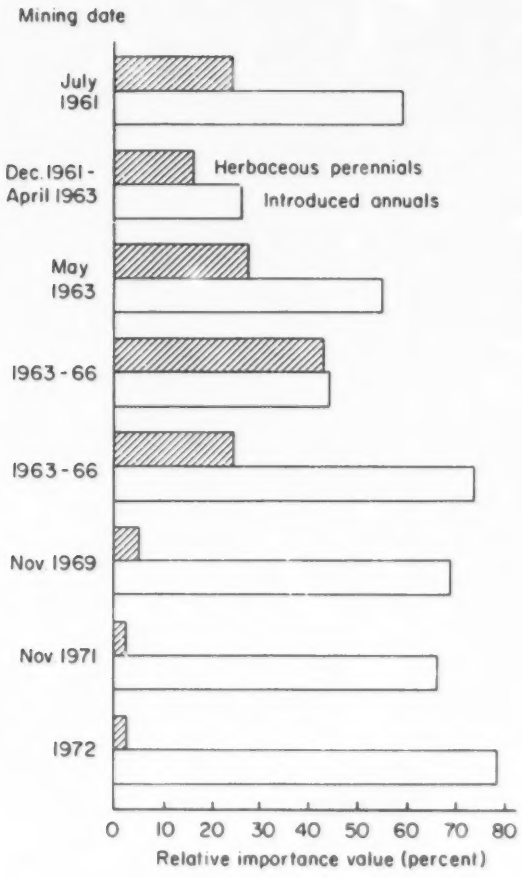

Figure 42.2. Relative Importance Values of herbaceous perennials and introduced annuals on the mined plots, McKinley Coal Mine, New Mexico.

Source: Wagner, Martin and Aldon (1978)

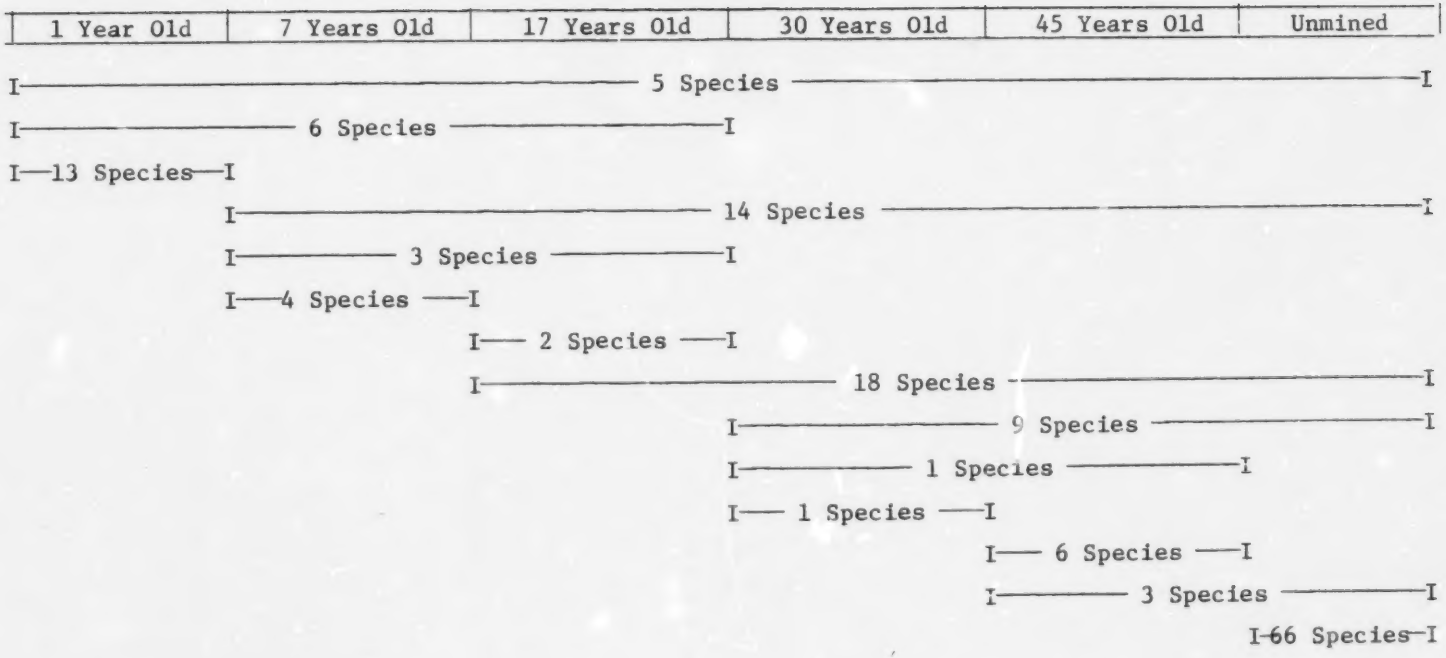

Figure 42.3. Vascular plant distribution patterns on spoil materials of different ages and unmined soils, Velva, North Dakota.

Source: Wali (1980)

The author found no general increase in vegetation cover with age, nor was there a clear relationship between age and dominant species. Listed by highest to lowest average cover, the seven dominant species for each area were:

1. Amsberry (5- to 7-). Populus deltoides, Ulmus americana, Rhus glabra, Aristida oligantha, Polygonum pennsylvanicum, Bidens polylepsis, Melilotus spp.
2. Fee (13- to 16-): Populus deltoides, Aristida oligantha, Echinochloa muricata, Bidens polylepsis, Polygonum pennsylvanicum, Poa pratensis, Acer negundo.
3. Harrison (17-). Melilotus spp., Echinochloa muricata, Bidens polylepsis, Populus deltoides, Polygonum pennsylvanicum, Acer negundo, Aristida oligantha.
4. Wilcox (22- to 23-). Melilotus spp., Bromus tectorum, Aster ericoides, Ulmus americana, Bidens polylepsis, Vitis riparia, Acer negundo.
5. Watertor (26- to 27-). Ulmus americana, Populus deltoides, Aristida oligantha, Acer negundo, Bidens polylepsis, Poa pratensis, Aster ericoides.
6. Klein (36- to 38-). Quercus imbricaria, Ulmus americana, Prunus serotina, Betula nigra, Rubus spp., Acer negundo, Aristida oligantha.

The seven dominant species comprised between 65 and 89% of total cover for each site.

Distribution by life history is given in Table 42.5. Species richness did not increase with age but was greatest on the area of intermediate age.

Richardson, Shenton and Dicker (1971) examined 237 pit heaps in 54 collieries in County Durham, England, ranging in age from 0 to over 80 years. The most common grass species were Agrostis canina, A. tenuis, Arrhenatherum elatius, Dactylis glomerata, Deschampsia flexuosa, and Holcus lanatus. Common herbs included Centaurea nigra, Chamaenerion angustifolium, Hieracium pilosella, H. perpropinquum, H. umbellatum, Plantago lanceolata, and Tussilago farfara. Betula spp.

Table 42.5. Percent distribution of species by life history and origin for six orphan Iowa coal spoils of different ages, and the number of species recorded in the transects from each area.

	Area						All areas
	Amsberry	Fee	Harrison	Wilcox	Watertor	Klein	
Age (years)	5 to 7	13 to 16	17	22 to 23	26 to 27	36 to 38	
Percent of Species							
Annuals	27	35	27	27	20	13	24
Biennials	6	7	7	7	4	8	9
Perennials	67	58	66	66	76	79	67
Native	83	72	79	75	81	86	80
Introduced	17	28	21	25	19	14	20
Number of Species							
	51	32	33	87	67	44	

Source: Glenn-Lewin (1979).

(B. pubescens, B. verrucosa), Crataegus monogyna, Rosa spp., Rubus spp., Salix spp., Sarothamnus scoparius, and Ulex europaeus were the most common trees and shrubs.

The authors could find no correlation between species and aspect. Carduus nutans, Plantago lanceolata, Rosa spp., Rubus spp., Senecio jacobaea, Acer pseudoplatanus, and Crataegus monogyna appeared in later successional stages, after 25 years, when there was some humus in the surface layers. Betula spp., Chamaenerion angustifolium, Centaurea nigra, Hieracium spp., Linaria vulgaris, Reseda luteola, and Ulex europaeus appeared as colonizers on some heaps and as late-comers on others.

Richardson and Dicker (1972) examined 12 colliery sites in England which had been planted to trees at varying times over a 30-year period. The surfaces had not been graded at planting time and thus there was minimal disturbance of the natural vegetation. By comparing vegetation in sites of varying ages the authors were able to study changes in species composition with time and relate these to succession.

Species which increased in frequency with age of spoil included Achillea millefolium, A. ptarmica, Aegopodium podagraria, Anemone nemorosa, Dryopteris felix-mas, Fragaria vesca, Heracleum sphondylium, Ilex aquifolium, Plantago lanceolata, Rubus fruticosus, and Taraxacum officinale.

The following species decreased in frequency: Agrostis tenuis, Anthyllis vulneraria, Calluna vulgaris, Centaurea nigra, Chamaenerion angustifolium, Chrysanthemum leucanthemum, Cirsium vulgare, Crataegus monogyna, Galium saxatile, G. verum, Reseda lutea, Rumex acetosella, and Ulex europaeus.

The authors noted that, as expected, grassland species (Agrostis tenuis) and early colonizers (Galium spp.) decreased in frequency as succession progressed while woodland species such as Fragaria vesca and Anemone nemorosa increased. As noted by Richardson, Shenton and Dicker (1971), several species retained the same frequency no matter how long the heap had been planted. The general trend however

was towards an overall decrease in species numbers as succession progressed.

Jonescu (1979) examined spoil piles in Saskatchewan dating back to the 1930s. The majority of species occurring on mid-slopes of overburden ridges (55 of 75) were members of Graminae (17), Compositae (32), or Leguminosae (6). Eighteen other families were represented. Total number of species did not vary greatly with age of spoil, nor did distribution of annuals, perennials, and exotics. Most species were native (58 of 75) and perennial (59 of 75).

In inter-ridge areas and adjacent prairie, 123 species were present; 66 were accounted for by prominent grassland families such as Graminae (26), Compositae (31), and Leguminosae (9). Twenty-seven additional families were represented. Ninety-six species occurred in the inter-ridge area; these were not categorized by family.

While only one tree (Acer negundo) occurred on the slopes, several, notably Salix, occurred in the inter-ridge area.

In summary Jonescu (1979:604) stated: "The findings show that ridge slopes in the strip-mined area, even after 40 years, were only 50% or less covered with vegetation. The vegetation was dominated by pioneer, weedy species such as Sonchus arvensis, Hordeum jubatum, Tragopogon dubius, [and] Grindelia perennis. Agropyron trachycaulum, Melilotus officinalis, Aster pansus, and Artemisia frigida were common as well. Cover per species was very low; with the exception of Agropyron trachycaulum (6%) even the most abundant species accounted for less than 5% of the cover. North and east aspects contained significantly more vegetation cover than did south and west aspects. No significant differences according to ages were found.

"Interridge areas contained a greater variety of vegetation and showed greater change in dominant species with time than did ridge slopes. Younger areas (1960's, 1950's) were dominated by Hordeum jubatum and Kochia scoparia in wet, dry, and mesic sites. Older areas (1940's, 1930's) showed different groupings of species found in adjacent prairies. Evidence of decreasing concentration of dominance (and increasing diversity) in older areas was interpreted as evidence of

juvenile populations being succeeded by increasingly stable vegetation. Moisture, age, and grazing were found to be the more important environmental gradients among more moist interridge and prairie sites.

"The degree of stability, in the interridges, as compared to the slopes, appears necessary for pioneer vegetation to become well established; within the interridge areas, the optimal environment of mesic sites has permitted more rapid progression from pioneer vegetation to vegetation more similar to undisturbed areas. In turn, increasing vegetation has contributed to stabilizing the substrate particles and providing organic matter in the network of interactions between vegetation and substrate. There is no evidence of such interactions of increasing complexity occurring on the ridges."

Montreal Engineering Company Ltd. (1977) examined old mine sites in the plains area of Alberta and compared naturally established vegetation on these sites to native communities in the same areas.

Standing biomass was found to be greater on a 32-year-old mine site than on native or tame grassland (Table 42.6). The yield was obtained without fertilizer and minimum reclamation input, but was protected from mowing and grazing. Major species occurring on the native and reclaimed grasslands are given in Table 42.7. Species present in parkland (forest/grassland transition zone) are shown in Table 42.8.

Within the mine area, five stages of vegetation succession were noted (Table 42.9). These areas were not grazed and the authors stated that adverse factors (soil conditions and grazing being most important) could change or halt development.

Melilotus alba and M. officinalis were the dominant initial invaders of raw spoil to the exclusion of most other species. The hypothesis is that after three to four years the Melilotus dies back quite suddenly and is replaced by Hordeum jubatum and numerous weedy species. As salts are leached, the H. jubatum is replaced by Bromus, which eventually dominates. The grassland stage may last 15 to 20 years. Salix and Populus begin to invade at that point (fire and moisture could change this sequence and time frame-Review Editor's

Table 42.6. Standing biomass at several grassland sites in the Plains area of Alberta, 1975.

	Jelters Grassland (Native) g/m^2	Black Nugget Grassland (Native) g/m^2	Jelters Grassland (Tame) g/m^2	32 year Black Nugget Mine Grassland (Natural Succession) g/m^2
July 5	197.6	225.5	264.0	314.2
	(1976)[a]	(2255)	(2640)	(3142)
August 30	308.4	294.0	ND[b]	444.5
	(3084)	(2940)		(4445)

Source: Adapted from Montreal Engineering Company Ltd. (1977). Used by permission of TransAlta Utilities Corporation.

[a] Figures in () indicate kg/ha.

[b] No data obtained due to mowing.

Table 42.7. Major species of the Black Nugget and Jelters Fescue Grasslands of Alberta (1975).

Major Species	Black Nugget		Jelters Native Grassland	
	% cover	% freq.	% cover	% freq.
Grasses	72.5		89.2	
Agropyron dasystachyum	0.8	10.0	3.4	53.3
Agropyron smithii	A	A	0.5	23.0
Agropyron subsecundum	A	A	P	--
Agropyron sp.	A	A	0.8	26.7
Agrostis scabra	P	--	A	A
Bromus ciliatus	A	A	P	--
Bromus pumpellianus	1.1	25.0	A	A
Calamgrostis inexpansa	A	A	0.3	3.3
Danthonia intermedia	A	A	0.6	13.3
Festuca scabrella	64.5	100.0	75.8	100.0
Koeleria cristata	0.3	5.0	A	A
Poa pratensis	A	A	0.6	10.0
Poa sp.	0.1	5.0	0.8	26.7
Stipa spartea	5.7	25.0	1.4	10.0
Forbs	17.8		20.1	
Achillea millefolium	1.5	55.0	P	3.3
Anemone cylindrica	P	--	A	A
Anemone patens	A	A	0.7	13.3
Artemisia frigida	5.5	90.0	P	3.3
Artemisia gnaphalodes	A	A	P	3.3
Artemisia ludoviciana	1.5	55.0	7.0	30.0
Aster sp.	1.8	35.0	0.4	16.7
Astragalus striatus	A	--	P	--
Campanula rotundifolia	P	--	P	--
Carex sp.	0.4	10.0	2.4	46.7
Cirsium arvense	0.7	15.0	A	A
Commandra pallida	A	A	0.7	16.7
Erigeron caespitosus	A	A	P	--
Galium boreale	5.6	80.0	5.0	56.7
Geum triflorum	P	--	P	--
Hedysarum alpinum	P	--	P	--
Heuchera richardsonii	P	--	P	--
Penstemon procerus	A	A	0.1	3.3
Potentilla arguta	P	A	P	--
Ranunculus sp.	A	A	P	--
Sisyrinchium montanum	0.2	10.0	0.2	10.0
Solidago missouriensis	P	--	0.1	3.3
Solidago sp.	0.5	5.0	P	--
Taraxacum officinale	0.1	6.7	A	--
Thermopsis rhombifolia	P	--	3.1	46.7
Vicia americana	P	--	0.4	16.7
Viola sp.	P	--	P	--

continued ...

Table 42.7. Concluded.

Major Species	Black Nugget		Jelters Native Grassland	
	% cover	% freq.	% cover	% freq.
Shrubs				
*Rosa arkansana	P		P	
*Rubus strigosus	P	--	P	3.3
	P	--	A	A

Source: Montreal Engineering Company Ltd. (1977).
Used by permission of TransAlta Utilities Corporation.
Note: P = present but not on transect
A = not noted on site
* = species in the Fescue Grassland but not belonging to the Festuca scabrella Association. They occur in grasslands which have been modified by grazing or mowing.

Table 42.8. Forest vegetation, Parkland area of Alberta, 1975.

	MOIST GROVE		MEDIUM GROVE		DRY GROVE		BLACK NUGGET RECLAIMED GROVE	
	Percent cover	Percent frequency	Percent cover	Percent frequency	Percent cover	Percent frequency	Percent cover	Percent frequency
Trees								
Populus balsamifera	A	A	A	A	A	A	0.6	1.9
Populus tremuloides	53.2	90.0	51.0	91.7	58.1	88.9	62.0	99.0
Σ Cover	53.2		51.0		58.1		62.0	
Tall shrubs (<2 m)								
Amelanchier alnifolia	6.8	16.7	4.3	8.3	6.9	11.1	A	A
Cornus canadensis	18.2	25.0	A	A	A	A	A	A
Populus tremuloides	2.5	5.0	10.9	35.0	A	A	0.6	2.9
Prunus virginiana	1.8	3.3	1.2	3.3	A	A	A	A
Salix sp	A	A	1.3	6.7	A	A	1.9	4.8
Σ Cover	29.3		17.7		6.9		2.5	
SMALL & MEDIUM SHRUBS (<2 m)								
Amelanchier alnifolia	8.4	43.3	1.3	10.0	A	A	A	A
Cornus canadensis	3.8	8.3	A	A	A	A	A	A
Populus tremuloides	0.7	6.7	0.5	8.3	0.8	5.6	1.4	6.7
Prunus virginiana	A	A	0.6	5.0	A	A	A	A
var *Melanocarpa*	7.3	30.0	A	A	A	A	A	A
Ribes sp	A	A	A	A	0.8	10.0	0.2	1.9
Rosa acicularis	7.4	51.7	9.9	38.3	20.3	78.9	12.5	32.4
Rubus strigosus	1.1	5.0	2.6	18.3	10.3	64.4	2.7	18.1
Symphoricarpos occidentalis	14.1	81.7	15.7	68.3	10.1	56.7	13.8	50.5
Σ Cover	42.7		30.6		42.3		30.6	
Forbs								
Achillea lanulosa	A	A	A	A	A	A	0.1	0.9
Actaea rubra	1.2	11.7	3.6	16.7	1.2	8.9	A	A
Aralia nudicaulis	11.2	43.3	1.6	6.7	A	A	A	A
Arenaria sp	0.1	3.3	0.03	1.7	A	A	0.001	1.0
Artemisia ludoviciana	A	A	A	A	A	A	0.1	1.9
Aster sp	0.6	11.7	0.3	6.7	0.1	4.4	1.5	36.2
Astragalus sp	A	A	0.3	1.7	0.03	1.1	A	A
Carex sp	0.02	1.7	0.4	16.7	0.6	5.6	A	A
Cirsium arvense	A	A	A	A	A	A	0.2	2.9
Cornus canadensis	0.1	3.3	0.5	10.0	A	A	A	A
Disporum trachycarpum	0.4	5.0	A	A	A	A	A	A
Epilobium (amputifolium?)	3.5	26.7	3.5	35.0	A	A	0.4	6.7
Fragaria vesca	0.3	8.3	1.3	21.7	0.8	13.3	0.8	9.5
Galium boreale	1.2	35.0	1.0	21.7	0.4	21.1	A	A
Hemicleum lanatum	2.9	18.3	0.1	1.7	A	A	A	A
Lathyrus ochroleucus	8.1	61.7	12.3	68.3	0.3	4.4	1.8	18.1
Melanthemum canadense	1.9	31.7	0.2	6.7	A	A	A	A
Melilotus sp	A	A	A	A	A	A	0.3	9.5
Mentha arvensis	A	A	0.1	3.3	A	A	A	A
Pedicularis sp	A	A	A	A	0.2	4.4	A	A
Potentilla sp	0.1	1.7	A	A	A	A	A	A
Pyrola sp	1.3	46.7	0.3	5.0	0.1	2.2	0.03	1.0
Pyrola asarifolia	0.2	3.3	A	A	A	A	A	A
Pyrola elliptica	A	A	0.3	5.0	A	A	A	A
Rubus pubescens	4.4	36.7	1.8	25.0	A	A	A	A
Senecio canadensis	0.8	8.3	0.2	3.3	A	A	A	A
Smilacina stellata	2.4	36.7	3.7	46.7	0.2	4.4	A	A
Solidago sp	0.1	1.7	0.2	5.0	0.2	2.2	2.1	18.1
Taraxacum lavigatum	A	A	A	A	0.1	3.3	0.8	14.3
Taraxacum officinale	0.1	3.3	0.3	11.7	0.1	5.6	0.1	1.9
Thalictrum sp	2.4	33.3	0.6	8.3	1.1	21.1	A	A
Thermopsis rhombifolia	A	A	0.1	1.7	A	A	0.01	1.0
Vicia americana	1.1	18.3	1.0	15.0	0.1	4.4	0.3	6.7
Viola adunca	A	A	A	A	0.2	5.6	A	A
Zizia aptera	A	A	A	A	0.04	2.2	A	A
Unidentified	A	A	A	A	0.01	1.1	A	A
Σ Cover	44.4		33.7		5.8		8.5	
Grasses								
Agropyron sp	A	A	0.2	13.3	0.8	7.8	A	A
Bromus sp	A	A	A	A	0.1	3.3	A	A
Bromus pumpellianus	A	A	A	A	A	A	0.3	2.9
Calamagrostis sp	A	A	0.5	15.0	A	A	A	A
Poa pratensis	A	A	A	A	13.3	66.7	A	A
Unidentified	1.0	43.3	1.2	26.7	A	A	0.9	35.2
Σ Cover	1.0		1.9		14.2		1.2	
No. of species	35		38		27		26	
Total Σ cover	170.6		134.9		127.3		105.4	

Source: Montreal Engineering Company Ltd. (1977: Table 3.4). Reprinted by permission of TransAlta Utilities Corporation.

Note: A = not in transect

Table 42.9. Stages of revegetation, Plains mine areas of Alberta.

Vegetative Stage	Time Frame	Typical Site
Forb stage	1 to 4 years	Black Nugget 9
Early grassland-weed stage	5 to 20 years	Black Nugget 8
Early grassland stage	20 to 30 years	Black Nugget 7
Grassland stage	30 to 50 years	Black Nugget 3
Early aspen parkland stage	50+ years	Dodds 2

Source: Montreal Engineering Company Ltd. (1977).
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comment) and by 30 years may form groves typical of aspen parkland. After 30 years the Bro us is gradually replaced by Poa and Agropyron, which are in turn replaced by Festuca, and weedy species die out. Species and cover changes with age are shown in Tables 42.10 and 42.11.

The vegetation of regenerating aspen groves indicated that 19 of 26 species were common with native stands. The remainder (e.g., Melilotus, Artemisia and thistles) are foreign to aspen grove vegetation (Table 42.8).

It has been suggested, that on account of the absence of agriculture in the western U.S. until quite recently, no highly competitive native annuals have evolved in the area and that the introduced competitive annuals (and more desirable introduced perennials) therefore are filling an ecological void in the regional flora.

It has also been suggested that revegetation efforts should concern themselves with the successional status of a species, rather than whether the species is introduced or native. Competitive weeds may be expected on nearly all reclamation sites and it may be more useful to plant introduced perennial grass species which establish easily and show some competitive parity with alien weeds rather than attempting to replant higher seral stage native species. Conversion programs may then be applied to a later date to encourage the establishment of native species when the sere has advanced to a point which favours their success.

42.1 SUMMARY

Very little research has been carried out on natural invasion onto mine spoils and what has been done is largely qualitative. Most studies have subjectively assessed old spoil piles with no information being available on spoil or environmental condition at the time of invasion.

Most invader species are wind borne. Topsoil and other amendments generally do not provide a suitable seed source for natural revegetation.

Table 42.10. Number of species present related to spoil age, Alberta.

Age of Spoil yrs	Numbes of Species Present				Total Species Present	Productivity	
	Grass	Herbs	Shrubs	Trees		g/m^2	kg/ha
2	4	10	ND	ND	14	438.2	4383
20	6	11	2	1	20	302.5	3025
32	7	35	6	2	50	444.5	4445

Source: Adapted from Montreal Engineering Company Ltd. (1977).
Used by permission of TransAlta Utilities Corporation.

Table 42.11. Cover of grassland areas on spoil piles, Alberta.

Age of Spoil yrs	Percent Cover		Bare Ground %
	Grass %	Herbs %	
2	5.3	79.1	15.6
19	39.4	49.4	11.2
31	67.4	36.9	--

Source: Montreal Engineering Company Ltd. (1977).
Used by permission of TransAlta Utilities Corporation.
Note: Total cover is over 100% due to formation of strata.

Many factors affect the success and composition of invading species. Aspect, slope, moisture, physical and chemical spoil properties, microclimate, external factors (e.g., grazing, fire) are all important. Mycorrhizal infection may also be important to the success of invading natives.

Heavily seeded and fertilized introduced (agronomic) species create an effective barrier to invading natives if above 20% cover; 20 to 40% cover allows some slow invasion; 40% cover is critical.

Plants from climax communities do not necessarily make good pioneer species in terms of competitiveness and vigour.

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43. ESTABLISHMENT OF SIMPLE VERSUS DIVERSE PLANT COMMUNITIES

The literature does not deal specifically with the problem of establishment of simple versus diverse plant communities, at least not in terms of quantitative research results. There is no lack of comment on the subject, although it is quite general and philosophical.

43.1 COMMERCIAL CROPS

The argument does not normally arise with respect to cereal and other commercial agricultural crops. Grains are planted as monocultures and forage crops have specific seed mixes. Areas are also tended and maintained by means of known cultural practices. There has been an ongoing argument in forestry with respect to monocultures versus mixedwood stands. However, this is a silvicultural problem and is not directly related to reclamation.

43.2 NATIVE AND OTHER NON COMMERICAL CROPS

The objective of reclaiming most wildlands is to create a self-sustaining vegetative cover that will provide adequate resources for whatever the end land use may be. Various possibilities are wildlife habitat (cover, forage, etc.), recreation, aesthetics, or simply erosion control. Whatever the use, a mixed cover is generally the objective; except in extreme circumstances, monocultures will not meet all requirements. The literature provides very little information on the subject. While many studies have tested species mixes, seldom are the reasons for success or failure of component individual species explained. Nor is it always clear why certain species are contained in the mixes, other than that they have proven to be successful performers. This is particularly true for agronomic and exotic species. Very little is known about native species; however, it is sometimes considered easier to select potentially effective or useful species by matching the native stands of surrounding areas. Unfortunately this does not always work as well as expected because successional traits are not considered.

When selecting species mixes, various environmental factors should be considered. Specific soil problems may exist and species may

be selected according to tolerance for such soil conditions (acidity, salinity, etc.). When climatic conditions are well documented and not extremely variable, species may be selected that are adapted. In such cases, a smaller number of species, perhaps even monocultures, may be acceptable, preferable, or perhaps the only solution.

When environmental factors are not well understood or quite variable, species mixes must be selected that will ensure good cover under all conditions. Disease resistance, drought tolerance, resistance to grazing and trampling, frost resistance, etc. are some characteristics that must be considered. Unfortunately, a mixture of species that meets these requirements may contain individual species that are antagonistic to others. Tall grasses may suppress more low-growing grasses; sod grasses may exclude bunch grasses or other life forms such as forbs or shrubs. The work of Walker, Sadasivaiah and Weijer (1977) and Walker and Weijer (1974, 1975) in Alberta is aimed at selecting lines of individual species that exhibit desirable characteristics. This will allow seeding with mixes of fewer species while maintaining desirable characteristics of a considerably greater number.

While competition is a factor to be considered when choosing grass mixes, it is far more problematical when mixing grasses, legumes, forbs, trees, and shrubs. Many authors (e.g., Fedkenheuer 1979a,b; Plass 1974, 1976; Vogel 1973) have found that grasses seeded for erosion control, particularly sod grasses, provide too much competition for space and moisture to allow shrubs and trees to establish. Dyrness (1975) found that grasses sometimes provided too much competition for legumes.

A major problem in many areas is the build up of small mammal populations in grass swards, with subsequent damage to establishing shrubs and trees. To date, this problem has precluded grass/shrub/tree mixtures on the tailings dikes in the Alberta Oil Sands. The entire problem area of inter-specific competition and selection of species with land use objectives in mind, requires considerably more study.

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44. POST RECLAMATION TREATMENT AND MAINTENANCE

Proper management and monitoring of a reclaimed site is vital to maintaining its stability and should be included in any reclamation plan. The degree of management required in any given area will depend upon the end land use objectives and type of vegetation established as well as the physical and chemical characteristics of the reclaimed site. In addition to the above, problems with wildlife and the encroachment of weedy species may require attention.

Hawk (1973:42) has noted that "...on any soil site, the introduced plant community, over a period of years, will be invaded by native plants and eventually will revert to a native or near native composition that is adapted to that particular site. This process can only be prevented or delayed if the stand is specifically managed to prevent it...." Thus, those end land use objectives which are not compatible with the natural vegetation of the region will require the most management. The most obvious case is land returned to agriculture. Other reclaimed areas requiring a moderate to high degree of management are grassed roadsides and powerline or pipeline rights of way where plant height must be restricted to allow easy access.

Berg (1975:83-84), in discussing the reclamation of strip mined areas in Colorado with high forage production potential noted three management alternatives:

1. "...Intensively managed pastures. The most productive species for such a scheme would be a combination of alfalfa and one grass, probably smooth brome. Grazing would have to be carefully managed to control bloat; or the mixture could be hayed. Cicer milkvetch is an alternative non-bloat legume, however it is more difficult to establish and production probably is less than for alfalfa.

   "If the land goes into this use, then grading and topsoiling would need to be planned and controlled so that conventional farm machinery could be used. A problem here might be the woody stems and roots in the

topsoil removed from shrubland. If the land is reclaimed for this use it could later be converted to one of the uses mentioned below or even to small grain cropland. Revegetation with vigorous species such as alfalfa and/or introduced grasses would reqire appropriate and timely farming operations but not more intensive revegetation methods such as mulching.

2. "...Grazing....[The best method here would be to seed] a mixture of native herbaceous species. Western wheatgrass (Agropyron smithii) would probably be the major species, another species could be slender wheatgrass (Agropyron trachycaulum). Indian ricegrass (Oryzopsis hymenoides) and beardless wheatgrass (Agropyron inerme) could be used on the drier sites. These native species, with the exception of slender wheatgrass, have less seedling vigor and might require the use of a mulch in addition to appropriate and timely farming techniques to establish a stand and control erosion on topsoiled spoils.
3. "...Browse species...establishment....[The author noted that] this is by far...the most management intensive of the land use options....Problems can be anticipated in establishment methods: moisture competition and herbaceous species; erosion if herbaceous cover or mulch is not used; invasion by weedy species such as Canada thistle (Circium arvense); and damage by rodents. The biggest problem will probably be browsing of the small plants by deer. Control measures might include fencing, repellents, herd reduction, and creation or upgrading of alternate browse areas by burning, chaining and/or fertilization."

The author noted that end land use would probably involve a combination of all three of these practices. The need for high-quality management, particularly of grazing and browsing on the revegetated areas, cannot be overemphasized.

Important physical and chemical characteristics of the site which will determine the management requirements include final soil pH and salt content, texture, and nutrient status, as well as site topography and location (elevation, latitude).

44.1 MAINTENANCE FERTILIZERS

Fertilization is often necessary to establish vegetation on disturbed areas due to their low nutrient status. Because of the cost of maintenance fertilizers, however, research is ongoing to determine the length of time they need to be applied.

The USDA, Forest Service (1979) has indicated that on most western spoils, phosphorus can be applied once (which should be sufficient to start P cycling), but that nitrogen may have to be added every two or three years for up to 10 years on certain N-deficient soils. Such sites would include those with coarse-textured soils, subsoils, geologic materials, or high precipitation areas.

Studies have been reviewed in Chapter 36 which attempted to define the length of time that fertilizers need be applied. The findings of these studies are summarized here.

44.1.1 Mountains and Foothills Region

Macyk (1972, 1973, 1974a, 1975, 1976, 1977a, 1978a) in a four-year study on fertilization of coal spoils at Grande Cache, Alberta, found that a minimum of two years of fertilization was required to maintain a reasonable grass/legume yield (Table 36.15). Yields improved substantially with three years fertilization. In both the two- and three-year fertilized plots, yields were highest when the last fertilizer application was closest to the sampling date.

Unfortunately Macyk did not test any plots fertilized in 1972 and 1975 only. This would have provided a better indication of the maximum time span allowable between fertilizations.

In a second experiment at Grande Cache, Macyk (1973, 1974a) found that removal of fertilization after two years caused a substantial reduction in yields (14 to 61%) of plots receiving higher fertilizer

inputs. Reduction of yield was much smaller (3%) in plots receiving lower levels of fertilizer input.

Ziemkiewicz (1979) studied the effects of removal of maintenance fertilizers after three years on coal spoils at two high elevation sites near Sparwood, British Columbia. In the subalpine site (elevation = 2100 m) removal of the fertilizer caused a severe decline in shoot and root production and a large accumulation of N and P in the undecomposed detritus on the plots. At the montane forest site (elevation = 1600 m) the effects of fertilizer removal were complicated by moisture stress conditions. However root and shoot production was not much different from that in the fertilized plots.

From these data Ziemkiewicz (1979:203) noted that "...two distinct phases in the development of reclamation plant communities were identified. The immature phase is characterized by a small root system that undergoes little yearly attrition, and a major portion of the system's available nutrients are transferred from the shoots to the detritus in the fall. Consequently, unless rapid detrital decomposition occurs the plant community becomes nutrient deficient and quickly loses productivity. N and P are immobilized to the greatest extent in surface detritus while K is leached from the detritus. The slow decomposition of detritus is aggravated by cold and dry conditions. Therefore, the high elevation areas are most likely to experience N and P deficiencies and require longer periods of maintenance fertilization, particularly with N and P.

"The mature phase is recognized by a rapid detrital decomposition and a larger root system which undergoes a high rate of turnover each year. The large root turnover places a large cycling pool of nutrients in the soil which mineralizes rapidly. These communities no longer require maintenance fertilization. Indeed, fertilization in a drought year can damage a mature reclaimed area.

"Mature reclamation plant communities should not be fertilized. Immature plant communities should be....[While] there is no indication of how long the mature communities will persist, they will at least persist several years after fertilization is discontinued with

little drop in productivity. The immature communities will decline rapidly in productivity immediately after the discontinuance of fertilization. They will not, however, die off immediately. Most of the plants will survive for at least two years though production will fall drastically."

Ziemkiewicz also provided some recommendations for maintenance fertilization of sites at these elevations:

1. Use of 200 kg/ha 10-40-10 fertilizer should provide adequate nutrients.
2. Fertilization should be completed by the third week of May at low elevation sites and the first week of June at high elevation sites. These dates usually coincide with the first evidence of shoot growth in the reclaimed areas.
3. Late season applications of ammonium sulphate or ammonium nitrate should not be applied to green-up a site unless soil erosion is an immediate concern.

Berg and Barrau (1978) studied the effects of nitrogen additions over four years on two disturbed alpine sites in Colorado. At the first site (elevation = 3350 m, pH = 8.1, 20% slope, glacial till), 67 kg/ha nitrogen was added for one, two, three, or four years and ground cover was assessed at the end of the last season. Fertilization improved cover for all years; however, increases in cover were smaller for plots fertilized over three and four years (Table 36.28).

At the second site (pH = 6.5, 70% rock and gravel) nitrogen was added at 56 kg/ha over four years. At this site, further additions of N after the first year did not improve cover (Table 36.29).

From these data the authors have concluded that on N deficient coarse soils N should be applied in the first year and then again in the second or third growing seasons. Following this they suggest periodic inputs when N-deficiency symptoms develop (perhaps three or four years).

On the other hand, Ries, Sandoval and Power (1977, 1978) and Younkin and Friesen (1976) have shown that even with continued fertilization, yields on unfertilized plots soon come to equal those on

fertilized plots, suggesting that in some areas maintenance fertilizers are not necessary.

Three series of studies (DePuit and Coenenberg 1979a; Macyk 1972, 1973, 1974a,b, 1975, 1976, 1977a,b, 1978a,b, 1979a,b; Rowell 1978) have found that repeated fertilization of reclaimed areas can cause a marked shift in plant community structures. Macyk, and DePuit and Coenenberg found large decreases in the legume component of vegetation communities with repeated fertilization. Rowell, and DePuit and Coenenberg found changes in diversity of grass populations receiving maintenance fertilizers. Rowell found that Bromus became dominant in fertilized plots on tailings dikes near Fort McMurray. DePuit and Coenenberg found that Agropyron cristatum and Bromus inermis became dominant on fertilized coal spoils at Colstrip, Montana.

The authors of these studies recommended halting fertilization as soon as possible if a diverse plant community is the desired end product of reclamation.

Younkin and Martens (1976) seeded and fertilized two abandoned drill rig sites in the MacKenzie Valley in 1973, and then assessed the effects of a second fertilizer application in 1975. Cover was not significantly improved with refertilization at the first site, though biomass of Poa pratensis cv. Nugget and Festuca rubra cv. Arctared was increased. At the second site, cover of a complex seed mix was improved while cover of a simple seed mix was not affected by refertilization. The authors did not make any specific recommendations on refertilization frequency for this region.

Van Cleve (1977:440) noted that "...at the present time it appears that promoting recovery of disturbed surfaces in the arctic through the use of introduced plant species may only be a temporary measure. With the exception of a few grass species, surface cover production will probably not be maintained for longer than three or four years....Most species are undoubtedly beyond the limits of climatic adaptation, although nutritional relationships may be a factor over which management agencies can exert more control in order to improve plant growth. Reseeding some areas may be necessary to provide surface

stabilization before native plants can effectively colonize disturbed sites."

44.1.2 Plains Region

DePuit and Coenenberg (1979a) studied the effects of one, two, and three years of fertilizer input on growth of a grass/legume mix seeded onto coal spoils at Colstrip, Montana. Plots receiving fertilizer for the full three years had the highest production of grasses; however, production of legumes was lowest. Agropyron cristatum and Bromus inermis showed the greatest positive response to continued fertilization. The authors noted that native perennial grass development was reduced under continued fertilization. From this study the authors concluded that it may not be necessary (or desirable) to fertilize reclaimed areas repeatedly if a diverse plant community is desired.

44.2 LARGE AND SMALL MAMMAL USE

"Animal use of rehabilitated sites can be compatible with vegetation establishment and maintenance. Management plans that include use of the site by animals can be successful as long as the management team realizes that reclaimed areas may be more sensitive than adjacent rangeland, and that special standards govern their rehabilitation. For example, seeded areas sometimes will attract animals such as deer in numbers sufficient to damage the stand. Rodents and rabbits can also damage the vegetation. These animals are attracted by the lushness and palatability of the planted vegetation. Thus, if pressure from animal invasion becomes too great, steps should be taken to protect the site" (USDA, Forest Service 1979:67).

The USDA, Forest Service (1979) report has provided a discussion on the direct and indirect methods of controlling grazing pressure on reclaimed sites. The authors noted that indirect methods are often less costly than direct methods. Indirect methods for protecting a site against livestock include:

1. "Adding less palatable species to the seed mixture;

2. Salting away from the seeded area--no closer than 0.4 km;
3. Providing permanent water away from the seeded area; fencing out nearby water;
4. Adjusting the use of livestock on the site to allow plants to mature by using a temporary alternative area for grazing, or by requiring non-use during seedling establishment;
5. Moving livestock off the area when allowable use is reached on the revegetated site."

Direct methods include:

1. "Barriers. Metal or wood devices, varying from the common barbed-wire fence to brush piles...are effective.
2. Repellents. Those used to repel wild ungulates have some effectiveness on sheep and cattle...however, specific repellents to discourage livestock use have not been fully developed.
3. Herding. This requires the use of herders to keep animals contained on areas other than those recently reclaimed."

Indirect methods for protecting a site against wild animals include:

1. "Using plant species that are undesirable to deer and elk;
2. Using plant species that mature about the same time as native species;
3. Avoiding hay as mulch where it may attract big game;
4. Controlling the deer population through hunting permits, particularly in localized areas during plant establishment."

Direct methods for protecting a site against wild animals include:

1. "Barriers....Metal, plastic or wood devices, varying from woven wire fence to brush piles, which prevent browsing can be used. [Ten to 15 cm]...diameter plastic tubing

placed over trees or plants to be protected have been effective in the Northeast. Woven wire fences [2.4 m]... high are recommended to exclude antelope, deer, and elk. Slash piles over seedlings or plantings discourage browsing while the plants gain height.

2. Repellents....The effectiveness of repellents depends on the plant species to be protected and the availability of other vegetation in the area. It has been found that repellents may not be effective when the vegetation is being irrigated. Apparently, the lushness of the vegetation is so attractive to the animals that the repellents do not deter them....Some repellents and the animals they repel are listed in [Table 44.1]. Specific repellents to discourage rabbits and rodents have not been fully developed.
3. Herding. This can be achieved with noisemakers, such as metal cans or acetylene guns. Lights and mirrors have also been used, as have tethered dogs.
4. Poisoning. Small mammals may be controlled by poisoning.
5. Encouraging predator invasion. Roosts, rock piles, etc., will provide a habitat for predators and thus [help to] control small mammal populations."

44.2.1 North-east (Oil Sands) Region

Green (1978:iv-v) has written a review of the literature on techniques for the control of small mammal damage to plants. The following is an excerpt from the paper's abstract:

"Methods of controlling either the abundance of small mammals or the levels of damage that they cause can be classified as chemical, mechanical, or environmental controls. Chemical controls include the use of acute rodenticides, multiple-dose rodenticides, chemosterilants, and repellents. Mechanical controls include the use of mechanical barriers, sonic repellents, and various kill traps. Environmental controls include the provision of supplementary food supplies,

Table 44.1. Common animal repellents.

Compound	Animals repelled
Tetramethylthiuram disulfide	Rodents and deer
Bone tar oil	Carnivores
9, 10-anthraquinone	Birds
4, aminopyridine	Birds
0, 0-Dimenthyl-0-4-methylthio-m-tolyl phosphorothioate	Birds
3-chloro-p-toluidine hydrochloride	Birds

Source: Adapted from USDA, Forest Service (1979).

biological control (the use of predators or pathogens), genetic manipulation, and habitat manipulation. The range of techniques commonly used in the past or currently in use, the proposed new techniques, the advantages and disadvantages of the methods, and the feasibility of employing the methods in large scale control programs are discussed in the paper for each class of control methods.

"Control methods that rely on a reduction in the number of small mammals are not recommended as effective means of controlling the levels of small mammal damage. Population-reducing methods of control include the use of rodenticides, chemosterilants, kill trapping, genetic manipulation, and biological control. Population reductions that result from the use of these methods are only temporary and they affect the natural regulatory mechanisms of the population; as a result, the small rodent populations return rapidly to densities that are similar to or greater than those of the pre-treatment populations. Some of these methods also pose serious hazards to non-target species, often including man. Small mammal damage can apparently only be controlled through population reducing methods when the substantial reductions in the densitities of small mammals can be maintained.

"Control methods that rely on a reduction of the damage caused by small mammals appear to be both more effective and more preferable methods of controlling the levels of small mammal damage. Damage-reducing methods of control include habitat manipulation, the use of chemical repellents, the provision of supplementary food, mechanical barriers, and sonic repellents. Natural regulatory mechanisms are less likely to be affected, and increased breeding and survival responses (which are typical of reduced small rodent populations) are avoided. Direct and secondary hazards to non-target species are also reduced."

The author has reviewed the literature with an eye towards controlling small mammal damage on reclaimed areas in the Athabasca Oil Sands region. He noted that meadow voles (Microtus pennsylvanicus) were suspected of causing most of the small mammal damage to seedlings on the reclamation area. They are primarily herbivores that prefer grassland areas with dense cover. Bark consumption by this species is uncommon;

increased consumption of bark is indicative of nutritional stress. Two other small mammals commonly found in the region are deer mice (Peromyscus maniculatus) and red-backed voles (Clethrionomys gapperi).

The following is a summary of the control program suggested by Green (1978:58) for reclaimed sites in the tar sands region:

"A program that would include both the reduction of ground cover and the use of supplementary food is suggested as the most promising method of controlling small mammal damage on the reclamation areas in the...study area. Repellents might also prove useful in conjunction with the use of supplementary food. The main effect of reducing the amount of cover would be to reduce the suitability of the reclamation areas for habitation by M. pennsylvanicus and C. gapperi and presumably reduce the peak numbers of these species. Supplemental food could then be used to keep the lower populations of these two microtine species from consuming bark. The reduction of ground cover and the use of supplementary food would probably result in a higher density of P. maniculatus on the reclamation sites in comparison to untreated areas; but because this species is not known to consume bark, this increase would probably have no significant effects on the survival of the planted seedlings. The increase could, however, affect the natural reseeding of the area from the adjacent forested areas, as P. maniculatus is a seed consumer.

"The control program would not anticipate large reductions in the numbers of M. pennsylvanicus or C. gapperi, nor are such reductions necessary to reduce the amount of damage. Increased survival of the seedlings is instead expected as a result of less feeding pressure on the seedlings by the microtine rodents."

Michielson and Radvanyi (1979) and Radvanyi (1976a,b; 1978) have also studied the use of poison for controlling small mammal damage in the Athabasca Oil Sands region. Radvanyi used poisoned bait feeder stations containing oat groats treated with "Rozol", an anticoagulant rodenticide at a level of 25 stations per hectare. The study examined populations over a four-year period and attempted to assess rodent

damage to small (15 cm) trees planted into a previously seeded grass mixture.

Damage to trees (mainly by Microtus pennsylvanicus) was heavy, with up to 95% girdling on some species (Populus sp., Betula sp., Populus petrowskyana) (Radvanyi 1976a). Due to the experimental design, the author found it extremely difficult to show that removal of the rodents reduced tree damage; however, the poisoning program did reduce rodent populations (Figure 44.1).

From the four-year study, Radvanyi concluded that the population of small mammals causing damage can be controlled by placing a continuous supply of treated oat groats in feeder stations on problem areas. The meadow vole population was reduced and the three to four year population cycle curtailed after treatment on the four study grids. The reduction in population experienced did not, however, eliminate damage to saplings.

Specific conclusions from the study were (Michielson and Radvanyi 1979:60-61):

1. "There was an increase in the diversity of small mammal species inhabiting the reclamation areas...[over the four-year period].
2. "Age class, sex ratios and reproductive status of meadow voles and deer mice were skewed by poisoning. During...[the final year of study], on treated areas, no juvenile animals were captured and the percentage of subadults was reduced. The male to female ratio was equal for meadow voles and the male deer mouse population was higher than the female population on the control grids. On the treated grids the female population of both species predominated. Scrotal male mice were proportionally more prevalent on treated areas and the percentage of pregnant females was significantly lower than on the control grids.
3. "The...[884 m^2] mean home range of meadow voles is much larger than required for an animal to encounter a feeder

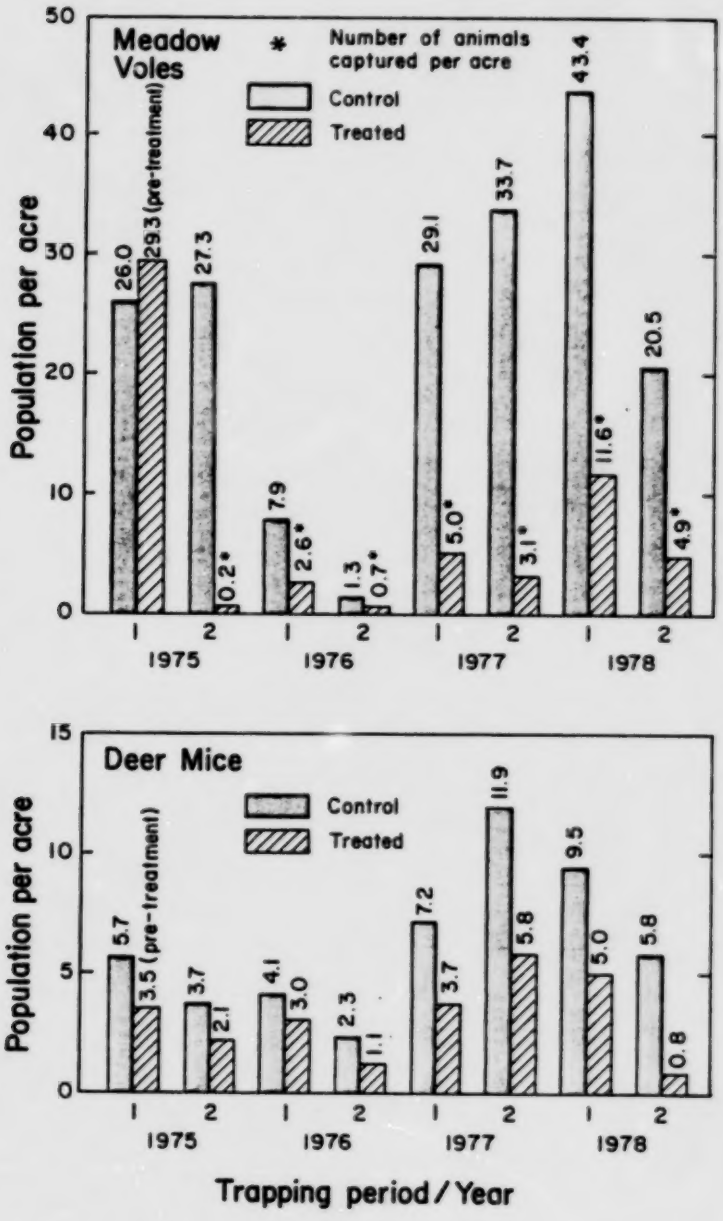

Figure 44.1. Population comparisons of the poison treated versus control grids for meadow voles and deer mice on the Suncor tailings dyke.

Source: Michielson and Radvanyi (1979)
Reprinted by permission of Suncor Inc.

station during normal movement. Each feeder must service...[400 m^2] at the present spacing arrangement.

4. "The population of meadow voles increased in the spring and decreased through the summer on a treated area rather than following the cyclic pattern experienced on control grids. Two factors could have caused the increase; increased transiency of the voles during winter and/or early spring or the reduced palatability of the treated groats in the spring coupled with the growth of new vegetation, causing fewer deaths by poisoning. Increased reproduction could not be a factor because the majority of animals are adults indicating a low reproduction rate or a lowered survival to partuition of new born animals.
5. "Deer mouse populations decreased to a lesser extent than meadow vole populations. The larger home range of the deer mouse could provide a constant source of new animals to the treated grids. It is not possible that the poison is not as effective on deer mice as meadow voles since all animals captured were new, not survivors from the previous trapping periods. On control grids many animals captured during one trapping period were recaptured during the next period.
6. "A rapid decline was noted after the peak spring meadow vole population of...[the last season]. Since lush vegetation persisted throughout the summer resulting from good growth conditions, lack of adequate suitable habitat was not the cause of the decrease. Reduced reproduction would account for a portion of the decline but would not account for the lack of recaptures of meadow voles from the spring trapping. During spring trapping meadow voles were recaptured from the...[previous] fall trapping period on all control grids. A number of deer mice were recaptured from the spring captures."

The authors felt that further studies were necessary to provide a link between decreasing population and tree damage. He also felt studies on the specificity of the method should be carried out to prevent non-target species being poisoned.

44.2.2 Plains Region

Hofmann et al. (1977) have studied the effects of grazing on forage production and animal performance on a reclaimed coal strip mine near Center, North Dakota. The site had been reclaimed in 1973 without benefit of topsoil; however, the authors noted that spoils were not high in sodium.

A mixture of Bromus inermis, Agropyron desertorum, Agropyron intermedium, Medicago sativa, and Melilotus officinalis was seeded at the site in spring 1973. Except for M. officinalis, these species predominated at the start of the grazing study, constituting 99% of the live vegetation as determined by point-frame quadrats. The vegetation was not clipped or grazed before the start of the study in 1976.

Duplicate pastures of 0.7, 1.4, and 2.1 ha were fenced on the reclaimed area. Each of the six pastures was stocked with three yearling Hereford steers, producing a stocking rate of 0.24, 0.48, and 0.72 ha/animal for heavy, moderate, and light grazing intensities, respectively. Within each pasture, two 15 m x 30 m exclosures provided controls of ungrazed areas throughout the duration of the study. Six 1.2 m x 1.5 m cages were placed randomly within each pasture to provide a measure of the current season's growth.

All pastures were stocked the same day. All grazing was terminated the same day when an estimated half of the available vegetation for the grazing season had been grazed under the moderate stocking rate.

Steers used in the study were weighed daily for three days and sorted into uniform weight lots of three and assigned to each pasture. After removal from the pastures, they were again weighed daily for three days and the average weight was used to measure animal performance.

Vegetative dry matter production was measured at the beginning and end of the grazing season each year by clipping six 0.9 m x 3.0 m strips in the pastures and ungrazed exclosures with a sickle bar mower. Two 0.18 m^2 areas within each cage were hand clipped at the end of the grazing season to determine the dry matter production for each pasture in 1977. Each was cut leaving 4 cm stubble. All samples were oven-dried at 60°C to obtain dry matter yield.

At the start of the 1976 grazing season all plots had approximately the same density and composition. Grazing reduced production in all plots (Table 44.2) in 1976. At the start of the 1977 grazing season the heavily grazed plots had significantly lower dry matter content than the other treatments, and by the end of the season (30 days) there was no harvestable forage on the heavily grazed plots (Table 44.2).

Steer performance in 1976 resembled that experienced from grazing similar species on undisturbed land. As stocking rate was increased average daily gains decreased, but beef production per hectare increased if animals were removed from the pasture before their ADG decreased to zero. Weight loss evidently occurred in 1977 when steers on the heavily grazed treatment produced only 13 kg/head in 30 days, whereas those on the moderate and light treatments gained 27 and 29 kg/head, respectively (Table 44.3). The heavily grazed pasture in 1977 was overstocked for the forage available, and by the end of 30 days, the animals were barely maintaining their weights. The authors noted that the experiment may have been terminated too early to spot differences between the light and moderate grazing rates.

Hoffmann et al. (1977) noted that data have been collected for only one year in this study and also pointed out that it was difficult to attribute differences in forage yields in the two seasons solely to grazing pressure as the 1977 season was much drier in the spring. However they felt that there were no differences between grazing management required on strip mined land and grazing on surrounding pastures, based on the available data.

Table 44.2. Dry matter production of lightly, moderately, and heavily grazed pastures; ungrazed controls; and season production under cages on a North Dakota coal mine in 1976 and 1977.

Grazing intensity	Dry Matter kg/ha Initial	Final	Season
1976			
Ungrazed	-[1]	3374	-[2]
Light	-	2560	-
Moderate	-	2112	-
Heavy	-	756	-
1977			
Ungrazed	3073 a[3]	3468 a	3468 ab
Light	2958 a	2946 ab	3613 a
Moderate	2116 a	1820 b	2228 bc
Heavy	732 b	0 c[4]	1656 c

Source: Adapted from Hofmann et al. (2240).

1 No previous grazing effects. No dry matter data taken before grazing in 1976.

2 No cages used in 1976 because all pastures were ungrazed and considered the same.

3 Within column means followed by same letter not significantly different at 5 level according to Duncan's Multiple Range Test.

4 No harvestable forage after grazing in 1977.

Table 44.3. Initial and final yearling steer weights, average daily gain (ADG), and total beef production of pastures with light, moderate, and heavy grazing intensities on a North Dakota coal mine 1977.

Grazing intensity	Avg. weight Initial	Final	Avg. daily gain ADG	Beef produced
	kg/head		kg/head/day	kg/ha
1976[1]				
Light	236	293	1.0	81
Moderate	236	281	0.8	96
Heavy	240	279	0.7	167
1977[2]				
Light	296	325 a	0.9	41
Moderate	300	327 a	0.9	58
Heavy	296	309 b	0.4	55

Source: Adapted from Hofmann et al. (2240)

1 55-day grazing season in 1976.

2 30-day season in 1977.

DePuit and Coenenberg (1979b) and DePuit, Willmuth and Coenenberg (1977) studied the effects of two types of grazing systems on plant production, animal response, and forage quality on reclaimed coal spoils at Colstrip, Montana.

Mining operations and spoils deposition at this site were completed in 1971, creating a rolling terrain of generally less than 3:1 gradient. In the spring of 1972, a mixture of native and introduced plant species was aerially broadcast seeded into a specially prepared, non-topsoiled seed-bed. The site was fertilized with nitrogen and phosphorus in 1972 and 1974. By the initiation of this study in 1976, the study site was covered by a mixed stand of predominantly introduced vegetation, with Agropyron cristatum, Bromus inermis, A. elongatum, Medicago sativa, and Melilotus officinalis the dominant species.

In 1975 and 1976 the 23.5 ha revegetated spoils site was subdivided into six pastures ranging from 1.9 to 4.9 ha in size to accommodate a completely randomized design of two treatments with three replicates, the treatments being moderate (i.e., 65% utilization) spring-fall grazing, and no grazing (control). Two additional pastures on revegetated spoils, similar in stand characteristics and age to the spring-fall grazed and control pastures, were created to serve as summer holding pastures for a portion of the stock. A suitable area of deferred, fenced native rangeland was used as a summer holding pasture for the remaining stock. Livestock used during the initial two years of study were yearling steers. Two grazing systems were examined: (1) rotated seasonal grazing exclusively on spoils vegetation, and (2) complementary grazing on spoils vegetation during spring and fall and rangeland during summer.

Parameters being monitored each year included vegetation production and species composition-diversity, forage preference, and nutritional quality. Data on plant production were collected in 1975 before initiation of the experiment and at the end of the second season (Table 44.4). The greater total productivity of the grazed pastures by the end of the second season was primarily due to A. cristatum, M. officinalis, and other perennial grasses. The authors found some

Table 44.4. Comparison of mean spring-fall grazed and ungrazed (control) spoils pasture aerial plant productivity prior to study initiation (1975) and after two years of the study (1977), Forage Evaluation study, Colstrip, Montana (production values in Kg dry weight per ha).

Plant Species/Class	Spring-Fall Grazed Pastures			Ungrazed (control) Pastures		
	1975 Prod.	1977 Prod.	% Change 1975-1977	1975 Prod.	1977 Prod.	% Change 1975-1977
Crested wheatgrass	1270	701	-44.8	970	231	-76.2
Tall wheatgrass	272	108	-60.3	192	54	-71.9
Smooth brome	325	173	-46.8	272	251	- 7.7
Other perennial grasses	102	129	+26.5	46	53	+15.2
Total perennial grasses	1969	1111	-43.6	1480	589	-60.2
Annual grasses	20	7	-65.0	29	1	-96.6
Alfalfa	nd[a]	377	nd	nd	592	nd
Yellow sweetclover	nd	476	nd	nd	7	nd
Other legumes	nd	46	nd	nd	16	nd
Total legumes	500	899	+79.8	492	615	+25.0
Forbs	nd	4	nd	nd	1	nd
Shrubs and half-shrubs	1	8	nd	7	T[b]	nd
Total aerial live biomass	2490	2029	-18.5	2008	1206	-39.9
Standing dead biomass	nd	117	nd	nd	584	nd
Ground litter (mulch)	nd	754	nd	nd	2774	nd
Total March-June Precipitation (cm)	23.9	17.0	-28.9	23.9	17.0	-28.9

Source: DePuit and Coenenberg (1979b)

[a] nd = not differentiated or determined

[b] T = trace (<1 Kg/ha)

measurable changes in compaction on the grazed plots; however, the slight increase did not seem to have any adverse effects. There were no apparent soil chemical changes in the grazed plots with the exception of a slightly higher organic matter content.

From this study the authors concluded that controlled grazing, as a management tool, may have potential as a reclamation practice to improve the condition of plant communities in certain reclaimed areas. They noted however that newly seeded areas must be given time for sufficient development to withstand impacts of grazing prior to any proper use of livestock to improve vegetation condition. From the data on forage quality and animal performance the authors have concluded that a management system employing spring and summer grazing on mine spoils and rangeland pastures, respectively, was much more effective than a system of continuous grazing on mine spoils.

Baker, Dingus and McCart (1976) found that satisfactory and economical beef calf gains could be obtained on surface mined land in Virginia reclaimed with Festuca arundinacea K31 and Lespedeza cuneata. They found that approximately 1.2 ha of a vigourous stand of these two species was required for grazing per beef cow and calf unit.

McArthur, Giunta and Plummer (1974) have discussed the seeding and management techniques required for many shrub species used in reclaiming disturbed areas for wildlife in Utah. Species discussed include (1) Artemisia spp., (2) Chrysothamnus spp., (3) Atriplex spp., (4) Purshia spp., (5) Cowania mexicana, (6) Fallugia paradoxa, (7) Symphoricarpos oreophillis and (8) Kochia prostrata. The reader is encouraged to obtain the report for further information.

44.3 CONTROL OF WEEDY SPECIES

Weeds may have to be removed from a rehabilitated site for a variety of reasons: they present a fire hazard, especially along roads; they are aesthetically displeasing; and they are noxious, or provide too much competition with desired plants. In certain instances, such as in pipeline and powerline rights of way, trees and tall shrubs are treated as weeds because they restrict access and interfere with lines. Both

mechanical and chemical means can be employed to control weedy species. In general, chemical means should be used only in highly selective situations such as control of noxious weeds (USDA, Forest Service 1979).

Mechanical means include:

1. mowing--weeds must be kept down below 15 cm;
2. shredding--needed for woody-type weeds; and
3. cultivation--last resort due to wind and water erosion and cost of operation.

Chemical means involve the use of plant regulators, which are any substance or mixture of substances that affect physiological action, growth rate, or other behaviour of plants. Plant regulators include:

1. herbicides;
2. defoliants (any substance or mixture of substances used to cause leaves or foliage to drop from plants); and
3. desiccants (any substance or mixture of substances used to accelerate the drying of plant tissues artificially).

The USDA, Forest Service (1979) stresses that herbicides can cause injury to humans, domestic animals, and wildlife. They should be used, therefore, with a great deal of caution. Herbicides should not be used over or directly adjacent to irrigation ditches, ponds, lakes, streams, or homes.

Though many reclamation studies have been conducted which include measurements of weedy species invasion, few of these studies have looked at their control. The use of amendments such as topsoil, mulches, and fertilizers, as well as irrigation tends to enhance growth of weedy species as well as seeded species. The most common weedy species invading disturbed areas in western Canada and the United States are Salsola kali and Kochia spp.

Lodhi (1979) studied Salsola kali to determine if there were any allelopathic chemicals in the plant which could be responsible for its rapid disappearance from early successional stages. The author found several phytotoxins in the leaves, including caffeic, ferulic, chlorogenic, isochlorogenic and neochlorogenic acids, and quercetin. Greenhouse studies found the decaying S. kali leaves reduced oven dry

weights of roots, shoots, and whole plants of both Kochia and S. kali but not of Melilotus officinalis. The author noted that the autotoxic response of thistle was common only on high stress areas such as mine spoils.

Day, Tucker and Thames (1979) tested S. kali as a mulch for reducing soil moisture losses from typical coal spoil materials. They found that a thistle mulch was as effective as a Hordeum vulgare straw mulch in reducing soil moisture loss in a greenhouse environment.

The authors pointed out that the main benefit of using a S. kali mulch over a H. vulgare mulch was that thistle grows naturally and prolifically on mine spoils, thus eliminating the cost of collecting and hauling H. vulgare from outside the mine area. They did not assess the ability of plants to grow in the S. kali mulched pots; thus, it is not known if any of the allelopathic effects noted by Lodhi (1979) would reduce the utility of this material as a mulch.

For the control of trees and shrubs along rights-of-way, Gillespie (1978) has advocated the use of planting strategies which would reduce the potential for invasion (e.g., thick grass stands) as opposed to the more common practice of selective cutting or spraying which is very expensive and labour intensive.

44.4 SUMMARY

Post-reclamation treatment varies according to end land use, species requirements, and external factors.

Post-reclamation fertilizer requirements are not yet well defined. Phosphorus needs can often be supplied by one application. However, nitrogen requirements may involve repeated application over two to ten years. Periodic application (every two to four years) is probably best, depending upon soil texture and precipitation regime.

Fertilizer may be required to promote biomass production and nutrient cycling. Immature communities require fertilizer; mature communities usually do not. Application of a good quality topsoil should reduce fertilizer requirements. It is not known how long it takes to reach stability of nutrient cycling; high elevation and northern environments require longer periods. In some instances unfertilized communities will eventually overtake fertilized

communities. In such cases "starter" fertilizers may be all that is required.

Timing of fertilization is important, particularly at high elevations and northern sites, to ensure efficient plant use.

Maintenance fertilizer may decrease plant diversity or may shift species dominance in the community (e.g., fertilization favours grasses over legumes and some grass species over other).

Reclaimed sites are more sensitive and less resilient than most natural sites, and are often more lush and palatable than surrounding natural communities. They are, therefore, subject to damage by domestic and wild animals. Domestic animal damage can usually be minimized by proper management. Wild animals must often be controlled or areas protected.

Studies have indicated that there is no difference in degree of management required on reclaimed strip mined land compared to unmined land. However, some management practices are not compatible with reclaimed land. For instance, continuous grazing on mined-land pastures may not be good practice and newly revegetated land must be protected for a sufficient length of time for it to develop stability and resiliency.

Reclaimed sites may be protected against domestic livestock by planting less palatable or undesirable species, grazing rotation, providing alternate attractive areas or other needs (such as water or salt), repellents, barriers, and herding.

Wild ungulate use may be regulated by planting less palatable or undesirable plants, barriers, repellents, herding, and population control. The latter may be accomplished by hunting, though probably not effectively. Rodents and other small mammals may be controlled chemically (rodenticides, sterilants, repellents), mechanically (barriers, sonic repellents, kill traps), and environmentally (supplementary food, habitat manipulation, genetic and species manipulation, biological control). Rodenticides, sterilants, kill traps, genetic control, and biological control are not recommended by some researchers as population reductions are temporary, natural

population regulation is affected, and non-target organisms may be affected.

Control of weed species is required to reduce fire hazard, improve aesthetics, and reduce competition. Mowing, shredding, or cultivating are acceptable mechanical measures. Herbicides, defoliants, and dessicants are chemical possibilities. The latter must be used with care to avoid injury to humans, and domestic and wild animals.

Many cultural methods (irrigation, topsoiling, fertilizers) may enhance growth of weedy species more than desirable species. This problem is often short-term in nature and may be limited by proper cover crop establishment. However, an improved understanding of species response to these treatments may lead to reduced post-reclamation maintenance cots. More research is needed on this subject.

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SECTION XIII

RECLAMATION OF SPECIAL SITUATIONS

45. RECLAMATION OF CORRIDORS

Corridors may be defined as long, narrow areas of disturbance, such as highways, seismic cut lines, and powerline or pipeline rights of way. An important feature of corridors is that they often cross several ecological zones, making it difficult to prescribe a single reclamation technique for any given type of corridor, or indeed even for a specific corridor. For this reason, amendments and seed mixes must be devised for a diversity of sites.

Reclamation treatments should be designed for easy application from road vehicles or aircraft as terrain may be steep or otherwise inaccessible.

45.1 HIGHWAYS

Erosion control is the most important aspect of highway reclamation, especially in areas where steep banks are created. Gallup (1974a:1) provided the following example in discussing the cost/benefit of roadway reclamation in the western United States:

"In 1972, approximately 11,000 acres [4455 ha] of National Forest road slopes were revegetated at a cost of about $4.5 million. The importance of this work in actual savings of money is evident from the following analysis: Effective slope revegetation can reduce soil losses from road slopes as much as 150 t (or about 76.5 m^3)/acre/year. An estimated $1 per cu yd [$1.31 per m^3] in road maintenance funds is required to remove the soil from the road ditches and repair gullies in the fill slopes. The reduction in soil loss achieved by revegetation would mean an annual savings of $1.1 million/year. In many areas, six years are required to establish native vegetation by natural means. The total saving, when the initial cost of $4.5 million is compared to the $6.6 million of road maintenance funds otherwise spent in 6 years, would be $2.1 million. Thus the benefit/cost ratio of successful roadside slope revegetation, $6.6/$4.5, is 1.47 to 1."

Goff (1971), in assessing the erosion problem associated with mineral exploration in the Swan Hills area of Alberta, noted that

approximately 1126 km of high grade road had been constructed in the area. Most of the roads had right of ways cleared to a width of 30.5 m.

Stanlake and Stanlake (1977), studying the effects of coal exploration roads on wildlife in British Columbia, have estimated that an average of 3 ha/km was disturbed by the roads on south to west facing subalpine meadows with a minimum slope of 30°. In areas where the slope was less than 30° or in the more stable, forested vegetation types, 1.5 ha/km was disturbed.

Brown, Johnston and Van Cleve (1978) and Van Cleve (1977) have noted that road construction and off-road vehicle use are among the most extensive and severe causes of surface soil disturbance in both alpine and arctic regions. They have conservatively estimated the extent of alpine soil disturbance related to roads in the western United States at 12 000 ha. They list physical disruption and compaction as the main types of disturbance but also note that the removal of the protective organic and vegetative cover in permafrost regions may result in erosion, changes in thermal and water regimes of the soil, and lower nutrient status and productivity.

Tiedemann et al. (1976) have noted that, in general, road cuts are far more difficult to revegetate than roadfills. They attributed this difference to variations in depth, texture, stability, and moisture-holding capacity.

Goff (1971:10), in a survey of erosion in the Swan Hills, noted that poor engineering during the construction phase was the major cause of the problem. He listed the following as common errors:

1. "Roads have been improperly located. In many cases they follow a straight line from one exploration well to another, regardless of land contour....
2. "Not enough consideration was given to maintaining water flow in the natural drainage systems.
3. "Culvert installations were too infrequent. This forced runoff waters to run long distances over bare ditch bottoms....

4. "Culverts and bridges were too small or improperly located....
5. "Insufficient use was made of diversion ditches to divert runoff waters into covered forest land.
6. "Few check dams to slow water flow in ditchbottoms.
7. "Excessive disturbances near streams and small watercourses.
8. "Little attempt was made to achieve soil stabilization by seeding of grasses and legumes.
9. "Diversion channels were not used to prevent water from running across long backslopes or land fills.
10. "Blocked drainages, causing silt buildup."

In addition to numerous articles dealing with revegetation of specific areas, several handbooks and reviews have been written in the past two decades on the subject of reclamation of highways. The following discussion identifies some of these publications and provides some indication of the topics covered by the authors.

Rothwell (1978a,b) has written a series of guidelines for the construction and reclamation of logging roads in Alberta's foothills and mountainous regions to minimize erosion, sedimentation, and deterioration of water quality. He noted that, in timber harvesting, as much as 90% of the sediment produced during logging operations comes from roads. The first paper deals primarily with materials handling and construction activities which can be used to minimize potential soil loss (Rothwell 1978a). A second paper discusses the use of brush mulches to reduce erosion and promote vegetation establishment (Rothwell 1978b).

Goff (1971:87-89) made several recommendations on reclamation measures for erosion control in the Swan Hills area of Alberta. Topics covered included: (1) landscaping; (2) seed-bed preparation; (3) season for seeding; (4) grass and legume varieties; (5) fertilization; companion crops; and (7) surface mulches.

The following is a summary of the recommendations:

1. "Re-landscaping is necessary to improve drainage characteristics where moderate to severe erosion damage is present. Levelling of rills and gullies provides a better growing surface. Leaving surface cloddy and roughened aids in moisture absorption and impedes runoff waters.
2. "The degree of seed-bed preparation undertaken had quite an influence on subsequent vegetation growth....Seeding on worked surfaces increases growth response. Spring seed applications needed to be worked into the soil... [fall seedings did not]....
3. "Germination and growth from spring seeding was retarded by climatic conditions and exposure. Companion crops of cereal grain sown with spring seed applications improved response, particularly with legumes....
4. "Grasses and legumes are rated in the following priority: Grasses: Timothy, Creeping Red Fescue, Kentucky Bluegrass, Crested Wheatgrass, and Bromegrass Legumes: Rambler Alfalfa and Red Clover [Late fall seedings were the most successful.]
5. "Fertilizer applications of...[224 to 280 kg/ha] of 16-20-0-14 ammonium nitrate-phosphate-sulphate compounds applied with the seed has given optimum results. A second application of...[56 to 112 kg/ha] was required the spring following growth of a companion crop.
6. "...Soil was...stabilized sooner by the faster germination and growth characteristics of cereal grains. Oli barley was found to be the most successful companion crop. Re-fertilization of the forage crop is necessary the following year due to the heavy drain of nutrients from the soil by the companion crop.

7. "The use of mulches was beneficial in two ways. Soil on steep slopes was stabilized until the vegetation was established and growing conditions were improved....Brush mulch...[was very useful in that the area is forested and it] can easily be applied with construction machinery."

Stanlake and Stanlake (1977:78) have made 10 recommendations for the reclamation of coal exploration roads in alpine areas of British Columbia. These recommendations are geared towards establishing wildlife habitat, primarily for ungulates. The following is a summary of these recommendations:

1. "Exploration roads do not need to be resloped since they do not constitute a hazard in most cases.
2. "On roads where the cutbank is very steep or overhanging for some distance, small runouts should be cut down the cutbank at major animal trails to prevent any interference of animal movements.
3. "In many cases, refilling road cuts with sidecast material is infeasible because the sidecast is far out of reach of any conventional machinery. Any operation of this kind would only partially refill the cut and still leave a smaller sidecast and cutbank and destroy any existing revegetation....
4. "Roads should be constructed in such a way as to protect the stability of the sidecast. On climbing roads or on contour roads that are pushed through unstable material or, where there is a large unstable sidecast, the road should be insloped, adequately ditched and the water removed where safe to do so....Roads should be off-sloped where...the sidecast material is stable enough to handle any ground water that may seep into it.
5. "The sidecast and cutbank should be seeded, as soon as possible after construction....From this point on, under no circumstances should any new material be pushed over the sidecast. In reopening the roads in the spring, any

slump should be excavated and hauled away. If the road surface needs grading, the material should be graded from both sides towards the centre.

6. "The road should be kept open and the drainage maintained until the revegetation of the sidecast is complete. In this way, any slumps after the road is closed that may divert runoff into the sidecast will not be harmful. When the road is closed, the surface should be seeded and access to the road carefully regulated.
7. "All adit refuse should be endhauled and under no circumstances pushed down the hill.
8. "Drill sites should be kept to a minimum size....
9. "Seam traces across hillsides should be eliminated because usually the last material that is pushed over the sidecast is coal which is very difficult to reclaim.
10. "Trenches should not be pushed straight down the hill as this causes a severe runoff problem....Trenches should be refilled and resloped prior to seeding."

Gregg (1976) outlined the methods used in reclaiming a 22.5 km stretch of highway in the Vail Pass, Colorado. The author discussed the planning that was done prior to highway construction and listed some of the techniques that were used in the reclamation phase. In the discussions, the author listed the pros and cons of each of the methods. Some of the topics covered were underground water, slope shape, seeding time and rates, topsoil, fertilization, mulches, and irrigation.

Nebauer (1973) has produced a set of recommendations and specifications for reclamation of mountain roadsides in New South Wales. The three major areas discussed were batters (slopes), drains, and culverts. Discussion in each of these areas centres mainly on the best construction methods to be employed; however, some mention of topsoiling requirements, suitable species, and maintenance inputs are made.

Wheeler and Vaartnou (1974) performed a general survey of reclaimed roadsides throughout Alberta, compared the species present with those originally seeded, and arrived at a list of species which

appear suitable for reclamation use in each of six soil types found in the province. Forty-four species were commonly found in the revegetated areas (Table 45.1).

Bennett and Donahue (1975) have written a manual dealing with the establishment of vegetation on construction sites where soils are infertile or of low productivity. The manual outlines potential methods for establishing vegetation types capable of attaining a stage of maturity and ground coverage within one season which will be an effective deterrent to erosion and transport of sediments. Full maturity and permanent-state coverage is expected within two to three growing seasons.

In addition to general recommendations, Bennett and Donahue provided detailed examples of successful highway reclamation procedures used in California, Idaho, New Mexico, Colorado, Texas, Mississippi, Virginia, West Virginia, Massachusetts, and Alaska. They also discussed: the selection and limitations of mulches; soil test interpretations; seed and seeding data for grasses, forbs, legumes and shrubs adapted to the western United States; and characteristics and seeding recommendations for grasses and legumes adapted to the mid-western United States.

Gallup (1974a,b) has produced a report on a survey of equipment and methods used in revegetating roadside slopes in U.S. national forests, primarily in the western United States. The report outlined the results of the survey on equipment (Table 45.2) and methods (Table 45.3) commonly used by the U.S. Forest Service, then discussed in some detail these methods. The discussion also includes some recommendations, drawn from the literature or field observations, that the author felt worthy of special note. The main topics covered were seed-bed preparation, seeding, and planting. A final section outlined some future developments in equipment which would aid in slope revegetation. Tiedmann et al. (1976) have also provided some recommendations for revegetating slopes in National Forests in Washington using shrubs.

Table 45.1. Species suitable for reclamation of roadsides in Alberta.

Species	Soil Zones
* Agropyron dasystachyum	Bl, DBl, GW
* A. smithii	Br -- GW
* A. trachycaulum	Br -- GW
Agrostis borealis	GW
* A. Gigantea	Bl, DBJ, GW
A. scabra	GW
Arctostaphylos uva-ursi	Bl, DBl, GW
Astragalus canadensis	TBl -- GW
Bouteloua gracilis	Br, DBr
Bromus pumpellianus	DBl, GW
Calamovilfa longifolia	Br, DBr
Deschampsia caespitosa	Br, DBr
* Elymus canadensis	Br, DBr
* E. innovatus	Bl, DBl, GW
Festuca brachyphylla	GW
F. ovina	DBl, GW
F. scabrella	BDr -- DBl
Glyceria pulchella	DBl, GW
* Hedysarum alpinum	TBl -- GW
Hierochloe odorata	TBl -- GW
* Koeleria cristata	Br, DBr, TBl
Lathyrus ochroleucus	TBl -- GW
Lupinus argenteus	DBl, GW
Medicago falcata	DBl, GW
* Oryzopsis hymenoides	Br, DBr
O. pungens	Bl, DBl, GW
Oxytropis sericea	Br -- DBl
O. splendens	Dr, DBr, TBl
Phleum alpinum	TBl -- GW

continued ...

Table 45.1. Concluded.

Species	Soil Zones
Poa alpina	Foothills & Mtns.
P. ampla	Br -- GW
P. compressa	DBl, GW
Potentilla tridentata	GW
⁂ Puccinellia distans	Br -- GW
⁂ Stipa comata	Br, DBr
⁂ Stipa spartea var curtiseta	DBr -- DBl
Trifolium medium	DBl, GW
Vaccinium myrtilloides	Bl, DBl, GW
V. vitis - idaea	DBl, GW
⁂ Vicia americana	DBr -- GW
⁂ V. cracca	TBl -- GW
⁂ V. sparsifolia	Br -- Bl

Source: Adapted from Wheeler and Vaartnou (1974)

Code	Soil Zone	Code	Soil Zone
Br	Brown	Bl	Black
DBR	Dark Brown	DBl	Degraded Black
TBl	Thin Black	GW	Grey Wooded

Table 45.2. Equipment currently used in roadside slope revegetation in U.S. National Forests.

Stage of revegetation	Name of equipment	Description	Support equipment	Function
Seed-bed preparation	Chain scarifier (clod buster)	Cable set with crossed spikes; weighted swivel at bottom end; cable hangs over bank	Tractor for drawing cable	Breaks up soil crust
	Sheepsfoot roller	Roller with rows of cylindrical projections. (Normally used for soil compaction on earth fills)	Crane or sideboom tractor for pulling roller up and down slopes	Breaks up soil crust and compacts slope
Seeding	Hydroseeder or hydromulcher	Truck-mounted tank with pump and nozzle	If needed: water tanker; flatbed trucks for mulch and fertilizer	Spreads seed, with or without fertilizer, mulch, etc., using water as a conveyance; range 76.2 m
	Cyclone broadcast seeder	Seed container with hand crank to throw out seed	None	Spreads seed manually
	Fertiblast gun	Air nozzle	Air compressor; holding tank for seed and fertilizer; pickup truck	Spreads seed using compressed air as a conveyance; range 22.9 m
	Rangeland drill and other commercial drills	Usually a two-wheeled implement including devices to make furrows in soil and cover seed applied through tubes	Tractor (towing vehicle)	Applies seed in rows and covers them with soil. Application rate of seeds may be closely adjusted. Depth at which seeds are put into soil may be closely adjusted
Mulching	Hydromulcher or hydroseeder	See above	See above	Applies mulch (wood cellulose products) with or without seeds, etc.
	Hay and straw mulchers	Large nozzle with blower, usually mounted on two wheels for towing. May have attachment to nozzle for spraying water or asphalt emulsion with mixture	Towing vehicle usually stake-side truck, with hay or straw on the bed for feeding the mulcher. Water trailer or asphalt emulsion trailer when needed	Spreads a mixture of hay or straw, seed, and fertilizer. Water may be applied to aid germination. Asphalt emulsion is applied to stick hay and straw particles together to prevent wind from blowing them off the slopes
	Straw compactor	Roller with yolk for towing. Prototypes were sheepsfoot roller with cylindrical studs removed and replaced by studs made of rectangular plates. Plates are designed to prevent pulling straw back out of slope	Side boom tractor or hydraulic crane for rolling up and down slopes	Pushes straw and seeds into the soil and compacts soil and mulch over seeds. Straw is pushed into soil to anchor it, thus reinforcing the soil
	Brush roller (conversion)[a]	Prototype roller similar to straw compactor but having studs mounted on concentric disks, allowing roller to flex over rock or uneven surfaces	See above	See above
	"Schmeiser (cultipactor)"	A roller similar to a farm disk harrow, but wider and having lugs on the rings. Concentric rings follow the contour of the ground	Tractor	Used on contract project to mix seed, soil, straw and fertilizer

Source: Gallup (1978a:9)

a Brush roller was developed by Charles A. Graham, USDA Forest Service Pacific Southwest Forest and Range Experiment Station, stationed at Fresno, Calif., in cooperation with the San Dimas Equipment Development Center.

Table 45.3. Methods and equipment used in roadside slope revegetation on 25 national forests.[a]

National forest and state	Seed-bed preparation	Seeding and planting: Grasses (seeded) with mulch or additive	Seeding and planting: Trees and shrubs, seeded or planted	Promoting germination and growth: Mulching[b]	Promoting germination and growth: Rolling	Work Crew	Estimated success[c]
Angeles - Calif.	Sheepsfoot roller	Broadcast		Straw	Straw compactor and Culti-pactor	Contract	Good
	Sheepsfoot	Broadcast		Straw	Straw compactor and Culti-pactor	Contract	Good
	Sheepsfoot	With mulch		Hydromulch and verdyol complex		Contract	Fair
	Sheepsfoot	Hydromulcher with Soil Seal				Contract	Poor
	Sheepsfoot	With mulch		Straw	Straw compactor	Forest Service	Good
	Manual	With mulch	Brush wattling	Straw		Forest Service	Good
Apache - Arizona & N.Mexico		With mulch		Hydromulch		Forest Service	Good
Black Hills - S.Dakota		With mulch		Hydromulch		Forest Service	Excellent
Boise - Idaho		Broadcast; with mulch	Native alder planted and seeded	Hydromulch		Contract	Good
	Chain scarifier[d]	With mulch	Wattling	Straw	Sheepsfoot	Forest Service	Grass - good Alder - poor
Carson - N Mexico	Top of cut slope ripped	Drill on upper part, with mulch on lower part	Native shrubs planted	Hydromulch and excelsior		Forest Service	Excellent
	Slopes terraced	Hydroseeder		Excelsior mat		Forest Service	Excellent
Challis - Idaho		Broadcast[e]				Forest Service	Good
Cherokee - Tenn.[f]	Not required[g]	During construction; with mulch		Straw with SS-1 emulsion		Contract	Excellent
	Not required[g]	During construction; with mulch		Wood chips with mulcher		Contract	Poor
	Slopes serrated	With mulch		Straw		Contract	Excellent
Cleveland - Calif.	Sheepsfoot	With mulch		Straw		Contract	Good
	Sheepsfoot	With mulch		Hydromulch		Contract	Good
	None (cut slope)	With Aquatain				Contract	Excellent
Coconino - Arizona		With mulch		Hydromulch		Forest Service	Not determined
Colville - Wash.			Native shrubs from Coeur 'Alene nursery			Forest Service	Good
		Portiblast gun				Forest Service	Good
Coeur 'Alene - Idaho		With mulch		Hydromulch		Contract	Excellent
		With mulch	Willow cuttings from nursery			Contract	Excellent
Gifford Pinchot - Wash.		With mulch		Hay		Forest Service	Good
Medicine Bow - Wyo.	Broadcast seeded during construction	With mulch		Straw		Forest Service	Not determined

Continued

Table 45.3. Concluded.

National forest and state	Seedbed preparation	Seeding and planting: Grasses (seeded) with mulch or additive	Seeding and planting: Trees and shrubs, seeded or planted	Promoting germination and growth: Mulching	Promoting germination and growth: Rolling	Work crew	Estimated success
Mendocino - Calif.		With mulch		Hydromulch		Contract	Good
Monongahela - W.V.		With mulch		Straw		Contract	Excellent
Pike - Colo.		With mulch		Hydromulch		Forest Service	Fair
			Nursery stock			Forest Service	Not determined
Roosevelt - Colo.		With mulch		Hydromulch		Forest Service	Good
St. Joe - Idaho		With mulch		Hydromulch		Forest Service	Good
Salmon - Idaho	Broadcast					Forest Service	Not determined
San Bernardino - Calif.		Contour seeded				Forest Service	Fair
	Smoothed, watered, rolled	With mulch		Straw	Studded roller	Contract	Good
	Smoothed, watered, rolled	With Verdyol Super		Hydromulch		Contract	Excellent
	Smoothed, watered, rolled		Native shrubs seeded			Contract	Poor
Sequoia - Calif.		Broadcast				Forest Service	Good
Sierra - Calif.	Crust broken with roller	Broadcast		Straw (manually applied)	Brush roller (modified)	Forest Service	Not determined
Umpqua - Oregon		With mulch		Hay		Forest Service	Good
		Hydroseeder with Aquatain				Contract	Not determined
Wasatch - Utah		Hydroseeder		Wheatgrass, straw with SS-1 emulsion		Forest Service	Good
		Hydroseeder		Straw with SS-1 emulsion		Forest Service	Good
Willamette - Oregon		With mulch		Hay		Forest Service	Excellent

Source: Gallup (1974a:10-11)

[a] Data gathered from interviews during the period March 1971 to December 1972, except as noted.

[b] Straw and hay mulches were applied by machine unless noted. Various hydromulching machines were used.

[c] No evaluation or comparison of equipment, products, or forest work is intended; project conditions varied widely and no specific conclusions can be drawn from the subjective judgments reported.

[d] Information from 1963 report on file at Boise National Forest.

[e] Vegetation seeded was unpalatable to cattle.

[f] All projects on Tennessee Forest Highway, Federal Highway Administration, District 15.

[g] Staged revegetation program allowed seeding of fresh slopes.

Leslie and Hornberger (1976b) have reviewed the literature and written a manual for highway reclamation which emphasizes an ecological approach to landscaping. The book includes sections dealing with: (1) the state-of-the-art of highway landscape development; (2) the variety of situations in the landscape development of highways, using five sites in eastern Pennsylvania as examples; (3) ecological effects of establishment and maintenance of vegetation; (4) a philosophy applicable to roadside reclamation with heavy emphasis on ecological principles and a man-nature harmony; and finally (5) a highly detailed approach to highway layouts with specific advice on how to plan highways and their reclamation.

The authors noted what they consider to be the three main approaches to highway corridor reclamation:

1. Grass turf; where grasses are maintained by frequent mowing and fertilization and large trees and shrubs are planted in aesthetically pleasing spots. A very expensive procedure.
2. Arrested succession; involves selective elimination of undesireable encroaching species through basal application of herbicides. The main objective is usually to maintain low growing species. The authors felt this approach is better than the grass turf approach but dislike the use of herbicides.
3. Natural succession; where an initially fertilized grass/legume mix is seeded then given no further management inputs (e.g., fertilizers, mowing). The authors noted that Vicia cracca is proving to be an excellent species in the U.S. (It is also used in Ontario-Review Editor's Note.)

Wright, Perry and Blaser (1978) and Green, Woodruff and Blaser (1973) have discussed methods of stabilizing disturbed areas and producing low maintenance vegetation for erosion control and aesthetics in highway corridors. The reports deal mainly with Virginia but the

authors stated the principles may be generally applied throughout the U.S.

The topics covered include: (1) topsoiling, (2) grading cut slopes, (3) mulching and binding agents, (4) seed mixtures, (5) fertilization, and (6) reseeding and improvement of older reclamation areas. Data from 11 mulching experiments (see Chapter 34), five species seeding experiments, and four slope grading experiments are presented.

From the above material Green, Woodruff and Blaser (1973:ii) have produced a series of "recommendations for implementation" for establishing vegetation or controlling erosion at any season of the year.

The following general conclusions were reached: "...Stair-step grading, shallow slopes, roughened soil surfaces, and incorporating lime and fertilizer reduced erosion per se or gave erosion control by establishing a vegetative cover quickly. Good grading practices with multi-step applications of seed and fertilizer if needed make topsoiling unnecessary....Altering seed mixtures with the addition of certain annual and perennial species has given marked improvements for establishing vegetative covers in various seasons of the year. Weeping lovegrass and German millet have significantly improved the establishment of vegetative cover in summer seedings, and cereal rye has extended the successful seeding dates in late fall-early winter. Such success with 'off-season' seedings has made it unnecessary to disturb soils a second time, thus avoiding additional potential erosion. Perennial species can be seeded with the 'temporary' species or in a second-step application during a favorable seeding season. Results with crownvetch in new seedings or on old slopes with sparse grass vegetation has been very successful, especially in northern and mountainous regions."

Schiechtl (1980) has written a comprehensive book on bioengineering techniques for severely disturbed areas such as highways, rights of way, slopes, and stream or riverbanks. Schiechtl felt that a bioengineering project could be regarded as complete only when it was no

longer obviously man-made, but appeared to be a work of nature. A bioengineer must combine the skills of the engineer, the learning of the biologist, and the artistry of the landscape architect.

The book has six main chapters dealing with: (1) technical preparation for bioengineering works; (2) bioengineering methods for earthworks; (3) waterways; (4) plant materials; (5) using bioengineering to its best advantage; and (6) the costs of bioengineering. The methods described in the book are extremely labour intensive and as such may find limited use for large projects. However they are very useful for small problem areas that may occur on highways and other corridor situations where space and choice of route are often restricted.

45.2 POWERLINE AND PIPELINE RIGHTS-OF-WAY

Schiechtl (1980) noted that rights of way must be accessible for inspection; therefore, only low growing vegetation can be used. Trees and tall shrubs may be suppressed through the use of cutting and selective herbicides (labour intensive and expensive) or through the use of grass mixtures which will help retard establishment and growth of unwanted species (Gillespie 1978). Dabbs, Friesen and Mitchell (1974) have pointed out the importance of understanding the construction techniques in laying a pipeline as these techniques will determine the amount and type of disturbance for which reclamation programs must be developed.

Wheeler and Vaartnou (1974) surveyed pipelines and powerline rights of way throughout Alberta to determine species which would be suitable for reclamation in these areas. Species suitability was determined for each of six soil zones found in the province. Fifty species were commonly found in pipeline areas (Table 45.4) and 56 in powerline areas (Table 45.5).

R.M. Hardy and Associates Ltd. (1976), in a proposed reclamation plan for an ethane pipeline from Empress to Red Deer, Alberta, made recommendations on: (1) soil surface stabilization methods; (2) topsoil salvage and replacement; (3) seed-bed preparation; (4) fertilization; and (5) seeding. Specific recommendations for

Table 45.4. Species suitable for reclaiming pipeline rights of way in Alberta.

Species	Soil Zone
Arctostaphylos rubra	GW
A. uva-ursi	GW DB1 B1
Vaccinium vitis-idaea	GW DB1
V. myrtilloides	GW DB1 B1
Viburnum edule	GW DB1
Rosa acicularis	GW DB1 B1 TB1 DBr Br
Ledum groenlandicum	GW
Cornus stolonifera	GW DB1
Amelanchier alnifolia	GW DB1 B1 TB1 DBr Br
Symphoricarpos occidentalis	GW DB1
S. albus	GW DB1 B1 TB1
Potentilla fruticosa	GW DB1 B1 TB1
Elaeagnus commutata	B1 TB1 DBr
Corylus cornuta	B1 TB1 DBr
Lonicera involucrata	GW DB1 B1 TB1
Prunus virginiana	GW B1 TB1 DBr
Vicia americana	GW DB1 B1 TB1
V. cracca	GW DB1 B1 TB1
Lupinus argenteus	GW BD1
Lathyrus ochroleucus	GW DB1 B1 TB1
Trifolium medium	GW DB1
Medicago falcata	GW BD1
M. sativa	GW DB1 B1 TB1
Oxytropis sericea	DB1 B1 TB1 DBr Br
O. splendens	TB1 DBr Br

continued ...

Table 45.4. Concluded.

Astragalus canadensis	GW DBl Bl TBl
Hedysarum alpinum	GW BDl Bl TBl
Agropyron trachycaulum	GW DBl Bl TBl DBr Br
A. smithii	GW DBl Bl DBr Br
Agrostis borealis	GW
A. gigantea	GW DBl Bl
A. scabra	GW
Bromus pumpellianus	GW DBl
Deschampsia caespitosa	GW DBl Bl TBl DBr Br
Elymus innovatus	GW DBl Bl
Festuca brachyphylla	GW
F. ovina	GW DBl
F. scabrella	DBl Bl TBl DBr
Glyceria pulchella	CW DBl
Hierochloe odorata	GW BDl Bl TBl
Koeleria cristata	TBl DBr BR
Oryzopsis pungens	GW DBl Bl
O. hymenoides	GW DBr Br
Phleum alpinum	GW DBl Bl TBl
Poa alpina	Foothills & Mtns.
Poa compressa	GW DBl
Poa palustris	GW DBl
Poa ampla	GW DBr Br
Poa pratensis	GW DBl Bl TBl DBr Br
Puccinellia distans	GW DBl Bl TBl DBr Br

Source: Adapted from Wheeler & Vaartnou (1974).

[a]

Grey wooded	GW
Degraded black	DBl
Black	Bl
Thin Black	TBl
Dark Brown	DBr
Brown	Br

Table 45.5. Species suitable for reclaiming power line rights of way in Alberta.

Species	Soil Zones[a]
Agropyron dasystachyum	Bl, DBl, GW
A. smithii	Br -- GW
A. trachycaulum	Br -- GW
Agrostis borealis	GW
A. gigantea	Bl, BDl, GW
A. scabra	GW
Amelanchier alnifolia	Br -- GW
Arctostaphylos rubra	GW
A. uva-ursi	Bl, DBl, GW
Astragalus canadensis	TBl -- GW
Bouteloua gracilis	Br, DBr
Bromus pumpellianus	BDl, GW
Cornus stolonifera	DBl, GW
Corylus cornuta	TBl -- GW
Deschampsia caespitosa	Br -- GW
Elaeagnus commutata	DBr -- DBl
Elymus canadensis	
E. innovatus	Bl, DBl, GW
Festuca brachyphylla	GW
F. ovina	DBl, GW
F. scabrella	DBr -- DBl
Glyceria pulchella	DBl, GW
Hedysarum alpinum	TBl -- GW
Hierochloe odorata	TBl -- GW
Koeleria cristata	Br, DBr, TBl
Lathyrus ochroleucus	TBl -- GW
Ledum groenlandicum	GW
Lonicera involucrata	Bl, DBl, GW

continued ...

Table 45.5. Continued.

Lupinus argenteus	DBl, GW
Medicago falcata	BDl, GW
M. sativa	TBl -- GW
Oryzopsis humenoides	Br, DBr
O. pungens	Bl, DBl, GW
Oxytropis sericea	Br -- DBl
O. splendens	Br, DBr, TBl
Phleum alpinum	TBl -- GW
Poa alpina	Foothills and Mtns.
P. ampla	Br -- GW
P. compressa	DBl, GW
P. palustris	DBl, GW
P. pratensis	Br -- GW
Potentilla fruticosa	TBl -- GW
P. tridentata	GW
Prunus virginiana	DBr -- GW
Puccinellia distans	Br -- GW
Rosa acicularis	Br -- GW
Stipa comata	Br, DBr
S. spartea var. curtiseta	DBr -- DBl
Symphoricarpos albus	DBl, GW
S. occidentalis	TBl -- GW
Trifolium medium	DBl, GW
Vaccinium myrtilloides	Bl, DBl, GW
V. vitis-idaea	DBl, GW
Viburnum edule	DBl, GW
Vicia americana	DBr -- GW
V. cracca	TBl -- GW

Source. Wheeler and Vaartnou 1974:8

[a]

Soil Zone	Code
Brown Soil Zone	Br
Dark Brown Soil Zone	DBr
Thin Black Soil Zone	TBl
Black Soil Zone	Bl
Degraded Black Soil Zone	DBl
Grey Wooded Soil Zone	GW

revegetation were made for river valleys, hummocky moraine, fine textured non-saline soils, fine textured saline soils, and sandy soils found along the proposed route.

Harrison (1979, 1980) tested several reclamation methods to determine the best strategy for revegetating an area along a proposed crude oil pipeline route through Jasper National Park, Alberta. Studies included effects of peat and sand amendments, fertilization, and four establishment methods.

Although the study is still in its early stages (third year) the author has made some general recommendations on suitable species and amendments for revegetating alpine disturbance areas. Four species, Agropyron pauciflorum, A. riparium, A. smithii, and Festuca saximontana, had good early emergence and therefore could be used in situations where erosion control is an important component of the rehabilitation. Agropyron pauciflorum, A. smithii, Poa pratensis, and Festuca saximontana showed good development characteristics and could be used for rehabilitation in the area. Of these, only Poa pratensis is an introduced grass; the remainder are native species.

Younkin (1976) has produced a series of preliminary recommendations for the reclamation of pipeline areas in the northern Mackenzie Valley, Northwest Territiories region. The author noted that these recommendations are very broad and must be refined by further site-specific experimentation on species suitability and management requirements such as fertilization. Dabbs, Friesen and Mitchell (1974) and Hernandez (1973) have also made recommendations for reclaiming pipeline rights of way in the mid-MacKenzie River Valley and mesic tundra areas, respectively.

Owen and Van Eyk (1975:varied pagings) studied the reclamation of a 54.9 km section of the Pointed Mountain (N.W.T.) gas pipeline and produced a series of three recommendations for reclaiming ecologically similar areas:

1. "In permafrost-free locations where erosion by flowing water is not expected to be a significant problem, natural revegetation by indigneous species should be

permitted to occur. Fertilization would probably enhance the rate of increase of vegetation cover.

2. "The trench over the pipeline should be refilled and bermed up during subsequent winter periods to prevent aggravation of gullying and be allowed to revegetate naturally on level terrain.
3. "Slopes that are subject to water or thermal erosion should be rehabilitated through the following intensive measures:
   (a) grading of the slope as close to the angle of repose of the substrate material as feasible;
   (b) eliminating concentrated flow of runoff and rainwater through properly constituted sandbag (or similar) breakers, oriented transverse across the entire face of the right-of-way slope; and
   (c) manual seeding of deep-rooting grasses over the slope, and planting of willow or alder cuttings, immediately following the main spring runoff. This step should be repeated until a continuous vegetation mat has been achieved."

45.3 SUMMARY

Road and highway rights of way reclamation has been well researched and numerous excellent comprehensive handbooks are available. This chapter is largely a summary of those reports.

Reclamation of road and highway rights of way and of exploration roads ("putting to bed") is carried out primarily for reasons of erosion control and aesthetics. The cost benefit of obtaining immediate cover on roadside rights of way is a definite plus.

Roads cause considerable disturbance in alpine and arctic regions and are difficult to reclaim. In general, road cuts are more difficult to reclaim than road fills due to types of materials and materials handling problems.

Poor engineering during construction is the major cause of erosion (road location, many aspects of drainage, excessive disturbance).

Transmission lines and pipelines must be reclaimed to low-growing vegetation to allow access and prevent interference with transmission lines. Herbicides, cutting, and vegetation manipulation are options for post reclamation management that must be considered when planning the reclamation program. Generally, the necessary information is available and recommendations have been made for reclamation procedures. However, controversy still exists, particularly for special-problem areas, and relevant studies are currently underway. Materials handling is the subject of most concern.

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46. CHEMICAL DISTURBANCE

Extracting and utilizing the natural resources of the earth results in numerous possibilities for undesirable disturbance and pollution of the land, when taken from the point of view of another land use. Many such disturbances or contaminations may be classed as chemical and include substances in the solid, liquid, or gaseous states. The discussion which follows deals with liquid and solid or particulate materials that are sometimes inadvertently or accidentally spread or spilled on land. Specifically, these materials are crude or refined oil, oily wastes, saline water or crystaline salts, and particulate elemental sulfur.

46.1 TYPES OF DISTURBANCE AND THEIR DAMAGE

46.1.1 Oil Spills

Rowell (1977) stated that half a billion barrels (79.5×10^9 L) of crude oil are produced annually in Alberta. Between 1971 and 1975 approximately 69 000 barrels (10.97×10^6 L) of oil were spilled, affecting about 81 ha of land annually. MacKay, Charles and Phillips (1973) pointed out that the larger the pipeline, the larger the spill. The causes of pipe failure and their relative importance in Canada and Alberta are:

Causes of Failure	Percent of Failures	
	Canada	Alberta
Corrosion, internal and external	60	29
Mechanical failure of pipe	30	28
Damage by other agencies	10	38
Miscellaneous reasons		5

In an oil spill cleanup manual published by the Concawe Secretariat (1974), the amount of oil retained by the soil is in the 15 to 40 L/m^3 range, depending on the nature of the soil and the dryness. The maximum depth of penetration can be estimated by:

$$D = \frac{1000V}{A \cdot R \cdot K}$$

where D = maximum depth of penetration (m)

V = volume of oil (m^3)

A = area of infiltration surface (m^2)

R = retention capacity of the soil (L/m^3). Some approximate R values for common substrates are:

Stone and coarse gravel	-5
Gravel and coarse sand	-8
Coarse to medium sand	-15
Medium to fine sand	-25
Fine sand to silt	-40

and K = approximate correction factor for viscosity, for example:

Gasoline	- 0.5
Kerosene	- 1.0
Light fuel oil	- 2.0

McGill (1976) observed that some of the problems resulting from oil spills often arise from poor or ineffective cleanup of spills prior to attempts at soil reclamation.

Westlake et al. (1976) extended oil spill studies to include the possibility of shale oil spills where the nature of shale oils becomes important. Raw shale oil is high in olefin and nitrogen and thus is unlike the crude oils, synthetic oils, or heavy oils from Alberta. They suggested that hydrogenation should be done at the extraction site prior to transport of the oil. As such, the oil would be more biodegradable if a spill should occur.

MacKay, Charles and Phillips (1973) predicted that two spills of several tens of thousands of barrels would occur per year on the MacKenzie Valley pipeline. These authors recognized three situations: (1) summer, when oil contaminates ground cover directly and will soak into the soil; (2) winter, when oil flows slowly and is affected by snow contours; and (3) spring, when oil is transported by gravity and water movement and a large area becomes contaminated although dilution occurs. Snow tends to limit the area of contamination because it absorbs the

oil. Winter spill cleanup is often possible by removing oily snow before it thaws.

Flashing from a spill results in loss of C_1 to C_4 hydrocarbons and a high percentage of the H_2S that is present in the oil. The total weight loss due to flashing is only about 0.1 percent. Evaporation is slower and may result in 30 percent mass loss on the first day and present a severe and widespread fire hazard. Mosses may become explosively inflammable when first impregnated with oil. The chemical composition of the oil, especially the H_2S content, needs to be known. Norman Wells crude loss on a lake surface was 22 percent in one hour, 35 percent in four hours, and 45 percent in six days. The probable time-temperature relationship on a moss surface for 35 percent loss was estimated to be one day at 21°C, four days at 0°C, 10 days at -17.8°C, and 30 days at -34°C.

Wein and Bliss (1973) mention that the thermal properties of the soil surface are changed by the destruction of vegetation and darkening effects of an oil spill. Toogood (1977) found that oil caused soil temperatures at the 15 cm depth to be 5 to 10°C higher than non-contaminated soils with the upward shift in temperature greatest with higher oil rates. However, they, as well as MacKay, Charles and Phillips (1973) found that oil spills had no affect on the permafrost layer and did not result in an increase in the active layer depth.

Experiments reported by Toogood (1977) included assessment of some physical characteristics of Black Chernozemic soils as modified by oil contamination. Oil-coated soils increased in wetting resistance as oil content was increased. On the other hand, hydraulic conductivity was not impaired and may even have been improved by oil contamination.

One of the spills reported by Rowell and McGill (1978) occurred about 25 years ago. No reclamation measures had been applied and most of the oil in the surface layers of the soil had decomposed. Small barren areas remained in the farm field where the soil was very dry, powdery, and hydrophobic. Three situations seemed to exist: (1) powdery soil that was difficult to moisten; (2) soils with oil seeps; and (3) fertile soils with residual oil below the rooting depth.

Oil contamination has a major effect on soil microflora. Sparrow, Davenport and Gordon (1978) studied the response of

micro-organisms in a sub-arctic taiga soil to hot (57°C) Prudhoe Bay crude oil applied at 15 L/m² in February and July. Numbers of heterotrophic bacteria increased relative to the control plot beginning immediately after the winter spill. The differences persisted until September. There was an initial depression in numbers of bacteria after the summer spill, followed by an increase (Table 46.1). Filamentous fungi propagules were reduced following the winter spill and remained so. The immediate impact of the summer spill was to reduce propagules in the surface horizon but by September counts were several times the control (Table 46.2).

Oil-utilizing bacteria and yeasts were significantly increased with the winter spill. Summer plots initially showed no increase, but by September significant increases were evident (Table 46.3).

Sexstone, Gustin and Atlas (1978), reporting on polygonal tundra sites contamination at 5 and 12 L/m², stated that oil generally resulted in enriched populations of micro-organisms at higher rates.

It is well known that oil spills damage vegetation but there have been some misconceptions. McGill (1977) found claims in the early literature that oils stimulated plant growth. However, he argued that the increased microbiological activity in soils caused by adding oil results in greater competition by the microbes with higher plants for the elements of plant nutrition. Microbes are the more effective competitors and higher plant growth declines because of lack of nutrition. Toxicity to plant tissue is primarily restricted to the more volatile hydrocarbons and these are rapidly lost from a properly aerated soil. Oil contamination, though, also affects plant growth by lowering the soil moisture-retention capability of the soil.

Baker (1970) discussed the general effects of oil on plants. In the paraffins, olefins, and naphthalenes the smaller, low molecular weight members are the most phytotoxic. The smaller molecules penetrate the plant surfaces and exert a smothering action. Benzene, xylene, and toluene are highly toxic and large polycyclic aromatics cause chronic forms of damage. Sunny conditions lead to wide open stomata allowing damaging oils to penetrate more easily. Roots may be less sensitive to oil than leaves or shoots. Within plant tissue the oil probably travels through intercellular spaces. Hutchinson, Hellebust and Telford (1974)

Table 46.1. Heterotrophic bacterial counts (X 10^6/g soil) in oiled and unoiled (control) plots in Alaska.

Sampling Time	Control Plot	Winter Plot	Summer Plot
A Horizon			
February[a]	2.8	5.4[c]	ND
June[b]	6.8	120[c]	ND
July	3.9	430[c]	2.8[d]
August	2.4	170[c]	340[c]
September	0.7	210[c]	640[c]
C_2 Horizon			
February[a]	1.2	1.8[d]	ND
June[b]	2.2	2.1	ND
July	0.9	41[c]	0.6[c]
August	1.4	14[c]	25[c]
September	0.3	12[c]	210[c]

Source: Sparrow, Davenport and Gordon (1978).

[a] Within 24 hours after winter oil spill.

[b] Within 24 hours after summer oil spill.

[c] Significantly different from the control at 1% level.

[d] Significantly different from the control at 5% level.

Table 46.2. Filamentous fungal propagule counts (X 10^4/g soil) in oiled and unoiled (control) plots in Alaska.

Sampling Time	Control Plot	Winter Plot	Summer Plot
A_1 Horizon			
February[a]	130	92[c]	ND
June[b]	120	14[d]	ND
July	120	18[d]	49[d]
August	34	23[d]	31[c]
September	24	10[d]	100[d]
C_2 Horizon			
February[a]	19	4[d]	ND
June[b]	24	0.7[d]	ND
July	13	8[d]	17[d]
August	14	4[d]	5[d]
September	5	2[d]	7[c]

Source: Sparrow, Davenport and Gordon (1978).

[a] Within 24 hours after winter oil spill.

[b] Within 24 hours after summer oil spill.

[c] Significantly different from the control at 5% level.

[d] Significantly different from the control at 1% level.

ND = No data.

Table 46.3. September plate counts (X 10^5/g soil) in oiled and unoiled (control) plots in Alaska.

Microbial Population	Control Plot	Winter Plot	Summer Plot
A. Horizon			
Yeasts	1	12[a]	590[a]
Proteolytic bacteria	1	120[a]	1100[a]
Anaerobic bacteria	4	36[a]	42[a]
C. Horizon			
Yeasts	0.2	3[a]	290[a]
Proteolytic bacteria	0.2	5[a]	370[a]
Anaerobic bacteria	2	5[a]	10[a]

Source: Sparrow, Davenport and Gordon (1978).

[a] Significantly different from the control at 1% level.

also mentioned that oil dissolves chlorophyll and reduces photosynthesis. Translocation in the phloem and xylem is reduced by blockage. Species that seem to have more resistance to oil damage belong to the Umbelliferacae and Gymnospermae.

The effect of oil contamination of the soil on seed germination was discussed in two of the papers reviewed. Rowell (1977) stated that germination is affected by 2 to 8 percent oil by weight in mineral soils but can withstand up to 10 times this percentage in organic soils [Review Editor's Note--since bulk density of organic soils (0.5 to 0.1 gm/cm^3) is about 1/2 to 1/15 that of mineral soils, the effect in terms of volume oil per volume soil could be similar]. McCown and Deneke (1973) found that oil affects germination and growth by disrupting plant water balances and interfering with plant metabolism. Seeds of fibrous-rooted plants were less susceptible to oil damage than seeds of trees or of tap-rooted plants. In the growth chamber experiments of McCown and Deneke, five plant species were germinated in Fairbanks silt loam at 60 percent field capacity with 0, 10, 20 or 30 percent Prudhoe Bay crude oil. Oil severely depressed germination and seedling biomass production.

Further experiments by McCown and Deneke (1973) compared fresh crude at 30 percent, aged in Fairbanks silt loam for 12 months before seeding Lolium multiflorum. Germination was as good as in the unoiled soil but the growth of the seedlings was only about 10 percent that of the control (Figure 46.1). Growth of Picea glauca in Fairbanks silt loam, contaminated with crude at 0 to 60 percent and aged for 12 months, was greatly reduced by increasing level of contamination (Figure 46.2).

Cook and Westlake (1973) also studied germination in oil-contaminated soil. They air-dried oil contaminated soil and non-contaminated soil from Swan Hills and tested germination rates of Hordeum vulgare in the soil kept at field capacity and 21.1°C with a 16-hour photoperiod. The oil reduced germination. They also published a table of the implications of amount of oil content of the soil on germination of seeds and growth of plants (Table 46.4).

Linkins, Atlas and Gustin (1978) discussed an experimental oil spill on polygonal tundra. Root respiration was significantly reduced and viable root biomass was greatly reduced by the oil (Table 46.5).

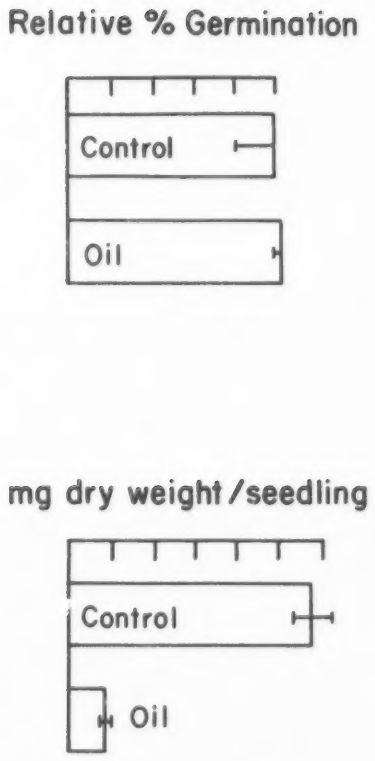

Figure 46.1. Greenhouse response of Lolium multiflorum to aged oil contaminated soil.

Source: McCown and Deneke (1973)

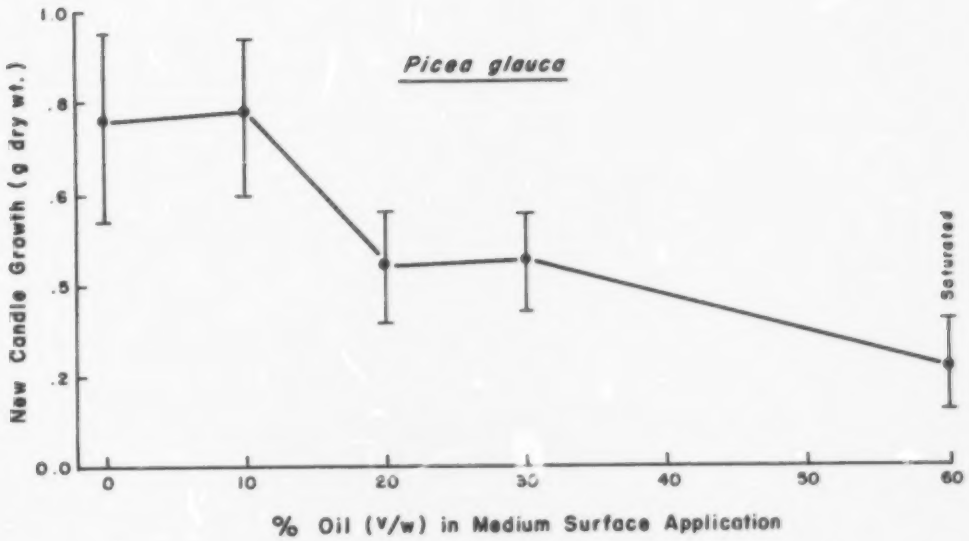

Figure 46.2. The growth response of Picea glauca in the greenhouse to increasing rates of oil contamination of an Alaskan soil.

Source: McCown and Deneke (1973)

Table 46.4. The relationship between oil content, seed germination and soil reclamation problems under field conditions in northern Alberta.

Oil Content (%)[a]		
Peat Soil	Mineral Soil	Implication
0-15	0.0-0.5	Seed germination and plant growth apparently normal.
15-30	0.5-1.0	Germination normal but careful management needed to sustain normal plant growth.
30-65	1.0-3.0	Germination slow or inhibited, frequent addition of fertilizer needed to keep plants alive.
65-200	3.0-8.0	Germination and plant growth strongly inhibited. Addition of fertilizer and creation of good aeration needed to biodegrade oil before plants can be grown successfully.
200+	8.0+	Physical and biological treatment needed before any hope of good plant growth can be expected.

Source: Cook and Westlake (1973)
Note: Natural levels of extractable hydrocarbons do not normally exceed 4% for organic soils or 0.1% for mineral soils.
[a] % oil by weight oven dry oil-free soil

Table 46.5. Viable root estimates (g/core) in oil contaminated polygonal tundra in Alaska.

	High Center *Luzula confusa*	Low Center Rim *Carex aquatilis*	Low Center Trough *Dupontia fisherii*
1975			
Control	2.60 (0.5)[a]	3.20 (0.40)	3.20 (0.40)
5 L/m²	0.90 (0.23)	1.12 (0.35)	1.79 (0.30)
12 L/m²	0.48 (0.13)	0.73 (0.20)	1.95 (0.42)
1976			
Control	2.0 (0.2)	2.70 (0.35)	3.75 (0.72)
5 L/m²	0	1.62 (0.20)	1.50 (0.60)
12 L/m²	0	0.80 (0.15)	1.40 (0.60)
1977			
Control	1.57 (0.5)	2.37 (0.24)	2.90 (0.1)
5 L/m²	0	0.26 (0.09)	0.66 (0.30)
12 L/m	0	0.24 (0.10)	0.48 (0.15)

Source: Linkins, Altas and Gustin (1978).
[a] Standard deviation in parentheses.

The authors observed that the effect of the oil on the roots of Luzula confusa was greater than on the roots of Carex aquatalis and Dupontia fischeri. This was due primarily to the drier high centre of the polygon soils and secondly because of the fineness of the roots of L. confusa. Plants with large, coarse, roots protected by a thick epidermis survived oil contamination of the high centre soils.

Wein and Bliss (1973), in assessing oil spill problems in the Arctic, studied the effect of applying 1300 to 2000 barrels (206 700 to 318 000 L) of fresh Norman Wells oil to tree-covered soil at Inuvik and to tundra at Tununuk Point and Tuktoyaktuk. All actively-growing plant tissues were destroyed. Initial recovery was evident three weeks after spring application of the oil by growth of lateral buds of dwarf shrubs, especially Salix and Betula. Carex spp. recovered more slowly. Only one moss showed any regrowth and lichens did not recover (Table 46.6). Recovery after a summer spill was slower. A winter spill caused more damage than expected because the toxic volatilities were not lost as quickly as anticipated. Total plant recovery ranged from 20 to 55 percent in one full growing season. The authors postulated that long-term effects on deeper rooted trees may continue as the oil penetrates more deeply into the soil.

Hutchinson, Hellebust and Telford (1974) reported on the effect of oil spills on taiga and tundra vegetation in the Northwest Territories. They also found that winter spill was still very toxic in spring. They noted a similarity between oil and fire damage. Several species showed a rapid loss of chlorophyll after exposure to oil that resulted in loss of photosynthetic ability. The weakened plants were more susceptible to frost damage in the fall or death over winter.

The Canadian Petroleum Association (CPA) has published a detailed 40 page manual or field guide for oil spill cleanup and reclamation which is particularly relevant to Alberta (Rowell 1978). It outlines a step by step procedure including spill documentation, initial containment and cleanup, damage assessment and reclamation planning, soil reclamation, revegetation, and post reclamation monitoring and assessment. The manual describes each step in detail, evaluating various cleanup and reclamation techniques such as diking, use of hay or straw as absorbents , flushing, trenching, and burning. Fertilization,

Table 46.6. Mean percentage cover and standard errors for species recovery in two Arctic community types treated with four levels of crude oil in June, July, and October.

Species	Crude oil treatment level											
	Control			Low			Medium			High		
	June	July	Oct.	June	July	Oct.	June	July	Oct.	June	July	Oct.
Willow-birch-heath (Tuktoyaktuk)												
Vaccinium vitis-idaea ssp. *minus*	9·1	9·1	8·1	2·T	3·T	2·T	3·T	2·T	3·T	2·T	T·T	1·T
Empetrum nigrum ssp. *hermaphroditum*	9·1	6·1	7·1	1·T	T·T	2·T	T·T	T·T	2·T	0	T·T	T·T
Salix spp.	5·1	7·1	8·1	2·T	3·1	4·1	2·1	3·1	6·1	1·T	2·T	2·T
Betula spp.	11·1	14·2	9·1	14·5	8·1	6·1	3·1	8·1	6·2	4·1	4·1	3·1
Carex spp.	3·T	5·1	4·1	2·T	4·T	2·T	2·T	2·T	1·T	1·T	T·T	T·T
Ledum palustre ssp. *decumbens*	4·T	4·T	6·1	4·1	2·T	3·0	2·T	2·T	2·T	2·T	2·T	T·T
Total live vasculars	48·2	54·T	48·2	20·2	22·2	21·3	15·1	18·2	25·3	12·2	9·2	6·2
Total mosses	75·2	78·2	68·3	0	0	T·T	T·T	0	0	0	0	0
Total lichens	2·1	3·1	4·T	0	0	T·T	0	0	0	0	0	0
Black spruce-alder-heath (Inuvik)												
Vaccinium vitis-idaea ssp. *minus*	12·1	13·1	17·2	1·T	1·T	1·T	1·T	1·T	1·T	T·T	T·T	T·T
Ledum palustre ssp. *decumbens*	10·1	10·T	11·1	5·1	4·1	4·1	5·1	5·1	1·T	6·1	6·1	5·2
Rubus chamaemorus	2·T	2·T	3·T	1·T	1·T	T·T	1·T	T·T	0	T·T	0	T·T
Total live vasculars	28·1	28·1	33·2	8·1	7·1	5·1	7·1	6·1	2·T	6·1	6·1	4·3
Total mosses	89·1	89·2	92·1	T·T	T·T	1·T	0	0	0	0	0	0
Total lichens	6·2	7·2	5·1	0	0	0	0	0	0	0	0	0

Source: Wein and Bliss (1973).

Note: T<0.5%. Measurements made one year after treatment.

liming, cultivation, and use of windrows are also discussed. Appropriate and inappropriate application of such techniques are identified. The emphasis on reclamation planning, pre- and post-reclamation sampling, assessment, and monitoring is particularly interesting. Among the useful information the manual contains are guidelines to plant stress and plant sensitivity to oil contamination (Tables 46.7 and 46.8).

46.1.2 Brine Spills

The magnitude of brine production accompanying the recovery of crude oil is greater than usually realized and will worsen as recovery technology and oil shortages increase. Rowell (1977) stated that, along with the production of oil, 200 million barrels (31.8×10^9 L) of salt water are produced in Alberta. Most of the oilfield brines are re-injected into the earth but accidental spills are inevitable. An estimated 39 000 barrels (6.2×10^6 L) of salt water are spilled annually. Together with oil spills, approximately 81 ha of land are affected each year in Alberta.

In Arkansas, Hileman (1974) reported on periodic flooding of land with oilfield brine. He estimated that 7284 to 9713 ha were affected by periodic flooding from oilfield pumping operations. The predominant ions of the Arkansas brine were sodium and chloride.

In Saskatchewan, White and DeJong (1975) indicated that brine contamination of land originates from overflow from old pits, spills from injection lines or from well-head gathering lines containing oil and salt water. The principal salt is presumably sodium chloride. The Saskatchewan brines, as reported by White and DeJong, contain 7000 to 200 000 ppm dissolved solids; 3000 to 70 000 ppm sodium, and 4000 to 120 000 ppm chloride. Innes and Webster (1981) reported on oil well brine composition from the Swan Hills, Alberta area including heavy metals, and macro- and micronutrient levels (Tables 46.9 and 46.10).

Salt water spills cause a severe reduction in the ability of the soil to support plant growth. An experiment by Envirocon Ltd. and Chemex Labs (Alberta) Ltd. (1975a) indicated that salt-contaminated soils from Virden, Manitoba did not support crop growth in the growth chamber without treatment. Hileman (1974) reported that brine flooded

Table 46.7. Expected damage to plant growth and soil properties in Alberta from contamination by crude oil.

Oil Content [a] (kg/m^2 to 15 cm)	Effect on Plant Growth and Soil Properties
0 to 1	No visible damage to plants or soil. Improved growth may occur.
1 to 2	Germination delayed, plant growth reduced and mildly nutrient deficient. Wettability of soil may be slightly impaired.
2 to 5	Germination inhibited, plants liable to serious nutrient deficiencies but growth can be maintained by careful management. Soil structure and wettability frequently very poor.
5 to 15	Germination and plant yields severely reduced. Soil structure and wettability very poor. Residual oil must be biologically degraded before reseeding can be attempted.
15+	Soil soaked with oil. Physical and biological reclamation measures needed before reseeding can be attempted.

Source: Adapted from McGill, Rowell and Westlake (1979), Biochemistry, Ecology and Microbiology of Petroleum Components in Soils. In Soil Biochemistry, Vol.5, E.A. Paul and J.N. Ladd (edits.) Marcel Dekker, New York.

[a] Initial oil content after spillage.

Table 46.8. Tolerance to oil of some Alberta plant species.

Common Name	Scientific Name	Relative Tolerance
Oats	Avena sativa	High
Reed Canary Grass	Phalaris arundinacea	High
Streambank Wheat Grass	Agropyron riparium	High
Alsike Clover	Trifolium hybridum	High
Sunflower	Helianthus annuus	High
Brome Grass	Bromus inermis	High
Cotton Grass	Eriophorum chamissonis	High
Buck-bean	Menyanthes trifoliata	High
Beggar-tick	Bidens cernua	High
Willow	Salix sp.	High
Dogwood	Cornus stolonifera	High
White Spruce	Picea glauca	Medium
Larch	Larix laricina	Medium
White Clover	Trifolium repense	Medium
Creeping Red Fescue	Festuca rubra	Medium
Barley	Hordeum vulgare	Medium
Timothy	Phleum pratense	Medium
Rapeseed	Brassica campestris	Low
Alfalfa	Medicago sativa	Low
Black Spruce	Picea mariana	Low

Source: Rowell (1978b)

Table 46.9. Analyses of Swan Hills, Alberta test brine Home Oil Battery A1.

Parameters	Concentration (mg/L) (ppm)
Cl	27 125
Na	15 755
Ca	2 130
Mg	270
SO_4-S	710
Br and I	74
F	2.6
CO_3	0
HCO_3	238
NO_3^--N	less than 0.02
NH_4^+-N	51
K	293
B	39
Fe	7.6
Co	4.21
V	1.55
Al	0.25
As	0.005
Cr	0.07
Hg	0.0002
Se	0.001
Ag	0.07
Mn	less than 0.1
Ni	less than 0.1
Pb	0.1
Cu	less than 0.08
Zn	less than 0.04
Cd	less than 0.02
total dissolved solids	45 592
pH	7.3
E.C. (mS/cm)	56.7
SAR	103.5

Source: Adapted from Innes and Webster (1981).

Table 46.10. Analyses of oil well brines of a number of fields and zones[a] in Alberta (mg/L) (ppm)

Parameters	Zones							
	Gilwood	Gilwood	Winterburn Basal Quartz		Pekisko	Pekisko	Viking	Viking
	Fields							
	Judy Creek	Swan Hills	Swan Hills	Swan Hills	Judy Creek	Swan Hills	Swan Hills	Judy Creek
Cl	132 570	132 000	93 000	42 097	40 293	31 328	24 800	13 670
Na	62 292	62 757	44 151	25 972	21 551	19 443	14 972	9 229
Ca	18 179	16 125	9 732	1 300	3 520	907	569	207
Mg	1 575	2 338	2 983	131	450	240	302	69
SO_4	314	150	1 164	280	Trace	489	12	Trace
CO_3	-	0	-	37	-	-	-	-
HCO_3	80	75	280	685	869	1 045	297	1 950
pH	6.2	6.5	7.1	7.8	6.8	7.9	7.2	7.3
E.C. (mS/cm)	189	196	123	80	106	65.8	58.5	36.9

Source: Innes and Webster ed. (1981)

[a] Energy Resources Conservation Board of Alberta Records

land supported only sporadic growth of unpalatable, salt-tolerant weedy grasses, rushes, and sedges. Webster (1976) listed the parameters of importance in assessing a salt-contaminated soil as:

1. Sodium adsorption ration (SAR) which, if over 25, indicates dispersion of soil colloids.
2. Exchange sodium percentage which, if over 5 percent, indicates poor soil structure.

Exchangable sodium at a value above 1 meg/100 g dry soil also indicates serious salt damage.

Webster (1976) stressed that there is a lack of information relating to the subject of salt spills in Western Canada and a need for testing methods for Alberta. Innes and Webster (1981) pointed out that the primary focus of previous work has been reclamation of agricultural lands affected by salt. Little information is available, therefore, on reclamation of brine contaminated forested lands.

Sump fluids from drilling operations can have markedly concentrated salt and organic levels. Vegetation damage following a spill of these fluids appears to result from salt toxcity (Strosher, Younkin and Johnson 1980). Thus they are included in this discussion of brine spills.

In a detailed study on land disposal of sump fluids, Strosher, Younkin and Johnson (1980) characterized the nature and problems of disposal and reclamation from typical Alberta sump fluids. Ten waste drilling sump fluids, representing the three basic drilling mud systems used in Alberta were chosen: (1) KCl/water/polymer, (2) dispersed water/gel, and (3) flocculated water/gel. The various sites, mud systems, and vegetation regions are listed in Table 46.11. Figure 46.3 shows the site locations and Table 46.12 provides additional vegetation and soils information.

As shown in Table 46.13 the KCl/water/polymer drilling mud system yielded the highest salt and organic contents ($\geq$33 000 mg/L ions and 10 000 mg/L total organic carbon). Thus as expected the KCl/water/polymer sump fluids were potentially the most harmful, significantly limiting or reducing seed germination, plant growth, and vegetative cover (Table 46.14). In field experiments sump fluid

Table 46.11. Mud system, site name and vegetation region of typical Alberta sumps.

Mud System	Site	Vegetation Region
Dispersed water/gel:	Fox Creek	Lower foothills
	South Brazeau	Lower foothills
	North Brazeau	Lower foothills
Flocculated water/gel:	Twining	Grasslands
	Pembina	Aspen grove
	Fir D-2	Lower foothills
	Pine Creek	Lower foothills
KCl/water/polymer:	F. Par	Lower foothills
	Bragg Creek	Upper foothills
	West Pembina	Lower foothills

Source: Adapted from Strosher, Younkin and Johnson (1980).

Figure 46.3. Locations of sump fluids study sites in Alberta.

Source: Strosher, Younkin and Johnson (1980).

Table 46.12. Soils and vegetation of Alberta sump sites.

Eco Region[a]	Vegetation Region	Soils	Vegetation Types
Boreal Uplands	Lower Foothills	Gray (Wooded*) Luvisols	Lodgepole pine, trembling aspen, balsam poplar forests and white spruce with minor inclusions of black spruce where fire has been dominant.
Boreal Northlands	Upper Foothills	Gray (Wooded*) Luvisols	Mature balsam and alpine fir forests.
Aspen Parklands	Aspen Grove	Dark Gray (Chernozemic)	Aspen forests with inclusions of balsam poplar, open areas of grassland and sporadic occurrence of white birch.
Mixed Grass	Grasslands	Dark Brown (Chernozemic)	Prairie grasslands.

Source: Adapted from Strosher, Younkin and Johnson (1980)

* Old terminology.

[a] Alberta Energy and Natural Resources: Resource Evaluation and Planning Division, 1980.

Table 46.13. Chemical analyses of Alberta sump fluids.

Sample	Total Organic Carbon	Organic Constituents as Organic Carbon (mg/L)				Inorganic Parameters				
		Polymers	Sulfonates	Hydrocarbons	Others	pH	Conductivity ms/cm	SAR	PAR[a]	Total Anions & Cations (mg/L)
Bragg Creek	10 100	5 500	<1	3 816	90.6	8.5	37.2	111.2	275.9	33 313
F. Par	405	237	53	5.8	39.2	8.5	6.2	35.7	29.0	5 679
West Pembina	295	184	42	4.4	25.2	8.0	17.5	87.3	111.9	11 872
Twining	76	55	3	0.9	4.0	8.5	2.4	35.6	2.8	1 877
Pembina	77	60	<1	4.2	1.9	8.0	2.4	10.0	0.5	1 376
Pine Creek	142	100	<1	22.5	4.2	9.3	1.5	12.3	0.1	2 168
Fir D-2	217	149	8	20.6	8.7	9.3	3.2	37.9	0.4	2 236
Fox Creek	30	12	12	0.3	2.2	8.1	1.5	3.8	0.6	847
South Brazeau	354	244	80	6.4	11.2	8.8	1.2	13.1	8.6	1 544
North Brazeau	307	208	51	1.6	7.7	8.8	2.0	18.2	4.3	2 001

Source: Strosher, Younkin and Johnson (1980)

[a] potassium adsorption ratio

$$\frac{K}{\sqrt{(Ca + Mg)}}$$

where K is activity of K ion in solution
Ca is activity of Ca ion in solution
Mg is activity of Mg ion in solution

Table 46.14. Summary of the results of field and laboratory investigations into the environmental impacts of ten Alberta sump fluids.

		SYSTEM TYPE, STUDY SITE AND TREATMENT									
		Dispersed Water/Gel Study						Flocculated Water/Gel			
		Fox Creek		South Brazeau		North Brazeau		Twining		Pembina	
	Year	Control	100 L/m^2	Control	100 L/m^2	Control	100 L/m^2	Control	L/m^2	Control	100 L/m^2
FIELD:											
Soil:											
Sum of major anions & cations[a] (ppm)	1	51	123	39	134	46	125	121	169	70	106
	2	39	43	101	66	35	66	39	80	ND	ND
Conductivity (0 to 15 cm) (mS/cm)	1	0.26	0.40	0.16	0.34	0.34	0.42	0.87	0.96	0.24	0.37
	2	0.24	0.25	0.60	0.20	0.20	0.20	0.43	0.50	ND	ND
Exchangeable Na (%)	1	1.2	2.7	0.7	0.3	0.3	1.9	1.4	0.5	0.2	0.4
	2	0.4	0.5	ND	ND	ND	ND	0.3	0.9	ND	ND
Tissue:											
Sum of major anions & cations[a] (ppm)	1	7507	11 294	2120	2330	4750	10 160	3990	4131	7375	7482
	2	7060	8180	2938	2790	4730	6500	2740	2370	ND	ND
Number of species treated		18		12		26		20		24	
Mean % living cover of control understory		59		94		75		54		73	
Mean % dead of total cover	1	5.5	4.1	1.2	6.3	9.1	10.1	22.0	21.5	5.7	5.1
	2	5.5	7.0	1.7	3.0	6.3	6.1	28.5	28.6	ND	ND
Reed canarygrass mean cover (%)	1	3.0	3.5	1.8	3.0	16.7	17.3	2.5	1.5	7.6	12.8
	2	5.0	4.6	35.0	26.0	48.5	65.0	ND	ND	ND	ND
LABORATORY:											
Soil[b]											
Sum of major anions & cations[a] (ppm)		143	670	148	1026	148	968	148	1050	148	1070
Conductivity (mS/cm)		0.87	0.85	0.87	2.80	0.87	2.30	0.87	1.25	0.87	1.25
Exchangeable Na (%)		0.73	0.90	0.73	4.20	0.73	5.00	0.73	2.20	0.73	2.40
Tissue[b]											
Sum of major anions & cations[a] (ppm)		6910	32 284	6910	26 400	6910	22 600	6910	14 490	6910	29 005
Percent germination (relative to controls)		90		56		66		79		76	
Mean productivity (g)[b]											
Initial (at 100 L/m^2)		7.6	7.0	8.0	7.3	8.0	7.9	7.6	8.7	7.6	9.7
Regrowth (at 100 L/m^2)		1.8	1.5	1.9	1.5	1.9	2.1	1.8	2.4	1.8	2.5

Table 46.14. Concluded.

		SYSTEM TYPE, STUDY SITE AND TREATMENT									
		Flocculated Water/Gel				KCl/Water/Polymer					
		Fir D-2		Pine Creek		F. Par		West Pembina [c]		Bragg Creek	
	Year	Control	100 L/m^2	Control	100 L/m^2	Control	100 L/m^2	Control	100 L/m^2	Control	100 L/m^2
FIELD:											
Soil:											
Sum of major anions & cations[a] (ppm)	1	51	93	81	81	189	452	ND	ND	57	2380
	2	36	91	74	96	62	91	ND	ND	105	184
	3	ND	ND	ND	ND	85	90	ND	ND	207	187
Conductivity (0 to 15 cm) (mS/cm)	1	0.21	0.24	0.46	0.31	0.48	0.90	ND	ND	0.44	4.10
	2	0.28	0.23	0.38	0.34	0.44	0.51	ND	ND	0.50	0.39
	3	ND	ND	ND	ND	0.50	0.50	ND	ND	0.60	0.40
Exchangeable Na (%)	1	0.8	1.2	1.9	1.7	0.2	0.7	ND	ND	1.3	4.7
	2	0.3	0.9	0.3	0.8	0.1	0.4	ND	ND	0.4	0.8
Tissue:											
Sum of major anions & cations[a] (ppm)	1	6634	9924	8059	9260	3050	7050	ND	ND	6852	37 000
	2	4180	5060	2470	2240	4250	3680	ND	ND	4150	9470
	3	ND	ND	ND	ND	2800	3750	ND	ND	3240	4390
Number of species treated		20		24		20		ND		12	
Mean % living cover of control understory		85		55		116		ND		23	
Mean % dead of total cover	1	3.7	3.3	2.1	5.0	6.4	29.4	ND	ND	5.1	26.1
	2	11.6	12.9	14.2	12.8	7.8	23.1	ND	ND	3.0	14.3
	3	ND	ND	ND	ND	6.9	10.1	ND	ND	4.8	7.7
Reed canarygrass mean cover (%)	1	ND	ND	26.2	17.5	47.5	11.2	ND	ND	1.8	0
LABORATORY:											
Soil[b]											
Sum of major anions & cations[a] (ppm)		148	995	148	791	148	1290	148	3434	148	5480
Conductivity (mS/cm)		0.87	1.25	0.87	0.89	0.87	2.30	0.87	14.80	0.87	6.50
Exchangeable Na (%)		0.73	1.40	0.73	1.70	0.73	4.20	0.73	9.90	0.73	8.10
Tissue[b]											
Sum of major anions & cations[a] (ppm)		6910	38 420	6910	34 175	6910	39 910	6910	61 700	6910	51 950
Percent germination (relative to controls)		79		64		30		14		18	
Mean productivity (g)[b]											
Initial (at 100 L/m^2)		7.6	7.2	7.6	8.1	7.6	7.6	8.0	4.9	7.6	3.1
Regrowth (at 100 L/m^2)		1.8	1.6	1.8	1.2	1.8	1.2	1.9	0.8	1.8	0.0

Source: Strosher, Younkin and Johnson (1980).

[a] Includes the major anions and cations (sodium, potassium, chlorides, sulfates) found in greatest concentration in fluid.

[b] Values in these sections are from the established plant section of the study.

[c] No data from native field trials because they were destroyed.

application at 12.5 to 100 L/m^2 (typical commerical application rates) reduced plant cover by 5 to 30%.

Other mud systems produced minimal or undetectable plant effects and have markedly lower salt and organic contents. Detailed studies of sump fluid composition indicated 83% of the organic constituents were unaltered mud additives. This included, primarily, (1) organic polymers, (2) hydrocarbons (comparable to diesel fuel), (3) lignosulfates, (4) polar O_2, (5) N and S compounds representing on an average 5% of the organic carbon, and (6) 12% unknown organic carbon forms (Table 46.13; Strosher, Younkin and Johnson 1980).

Vegetation studies indicated the salts and diesel fuel were the most phytotoxic. Significant plant stress occurred with application of 4000 to 8000 mg/L of salts and 2000 to 4000 mg/L diesel fuel. Diesel fuel-bentonite interaction can also reduce its toxicity. With $\geq$10 000 mg/L bentonite stress occurred at $\geq$ 16 000 mg/L diesel fuel. It was also evident salts accounted for over 90% of the plant stress observed.

Fish, bacterial, and seed bioassays were used to assess toxicity. Germination (seed bioassay) was very sensitive to salt concentration, insensitive to organic compounds, and thus highly correlated ($r = 0.83$) with plant stress. Conversely the fish or aquatic bioassay was very sensitive to organic compounds and not a good indicator of plant toxicity.

Plant stress was due to physical plant sump fluid contact and plant uptake. Following sump fluid application from four of the 10 sites, salt tissue levels were in the high to toxic range; however no known phytotoxic organic compounds were detected. Salt levels markedly decreased after the second season and were similar to the controls after the third season. As was found in the brine spill research in forested Swan Hill sites (Strosher, Younkin and Johnson 1980) salt damage to soil from sump fluids was low and ephemeral. Only high rates of KCl mud system fluids made the soil saline and produced significant levels of residual organic compounds after two seasons.

Soil salt migration or flux was determined or controlled by the soil physical properties, especially texture, as well as by the moisture regime. Maximum penetration after 15 months was 15 to 60 cm

for salts and 20 to 65 cm for organic compounds. Salt and organic compound lateral flux was $\geq$2 m. Thus most sump fluid constituents are readily removed from the rhizosphere with minimal long term effects. Some limited deep leaching down the profile of the more stable constituents causing some groundwater contamination is inevitable.

46.1.3 Particulate Sulfur

Nyborg (1974) stated that storage, handling, and loading of elemental sulfur at gas processing plants in Alberta have resulted in damage to less than 405 ha of land. However, more recent information suggests damage is much more widespread, particularly because of increased marketability of sulphur and the resulting breakup of large sulfur storage blocks. The damage results from oxidation of the sulfur, which leads to soil acidification. Plant cover is killed and the exposed soil becomes susceptible to erosion. Sulfur dust at 4.5 to 6.7 t/ha will acidify most soils enough to preclude plant growth. Rate of acidification will be accelerated by cultivation. Oxidation will continue until the pH of the soil is less than 2 at which point bacterial activity stops.

46.1.4 Other Chemical Disturbances

Goettel (1970) reviewed agricultural sources of pollution and pointed out that soil has a high degree of resilience in withstanding pollution. In addition to industrial sources of pollution, including oil spillage, salt water spillage, and sulfur dust contamination, he discussed urban and domestic waste disposal. The agricultural sources include biodegradable organic materials (primarily animal manure and crop residues), disease organisms, toxic agricultural chemicals, excess fertilizers, and concentration of salts and minerals.

Heavy loading of the soil may lead to excess nutrients and high biological oxygen demand which in turn leads to possible eutrophication of surface waters. Disease organisms are not a major problem in relation to proper domestic sewage disposal. Goettel stated that damage may occur from misuse or abuse of agricultural chemicals in Alberta. However, there exists legislation and regulation to control such practices.

Such statements, however, should be intepreted with caution. Pollution due to chemical disturbances from salt and oil spills, sulfur, and other chemical spills are much more serious than agricultural fertilization as point sources of pollution. In terms of spatial pollutant loading on a watershed, or province-wide basis, the N and P loading of surface and groundwater can be quite significant. Spatial estimates for large watersheds have not been undertaken as they have in some other parts of North America (personal communication, D. Graveland, Alberta Environment, Earth Sciences Division). Specific examples, however, of N and P polluted surface waters have been traced to agricultural sources (personal communication, D. Graveland).

Since much of the plains agricultural area of Alberta is a moisture deficit soil climatic regime and since water tables tend to be at significant depths, transport of nitrate-N from fertilization would be expected to be minimal. Recent research tends to confirm this (personal communication, D. Graveland). Wind and water erosion of P and N from the organic rich Chernozem type A horizons poses a more serious problem and some evidence of this has been documented in the Old Man River north of Lethbridge (personal communication D. Graveland).

46.2 TREATMENT AND REHABILITATION OF DISTURBANCES

46.2.1 Burning

Under the right conditions crude oil spills will burn easily. MacKay, Charles and Phillips (1973) stated that moss may become explosively flammable when first impregnated with oil. If the air is stagnant, there will also be a fire hazard from "flashing".

The flammable characteristic of an oil spill can be used to facilitate cleanup, as indicated in several papers. The Prairie Regional Oil Spill Containment and Recovery Advisory Committee (1976a) published guidelines for burning major (greater than 50 barrels (7950 L)) and minor (less than 50 barrels (7950 L)) spills under various conditions. They warn that fire hazards are high during May and June and special guidelines are required during this time.

McGill (1977) stated that burning can remove the last traces of oil at a site, help disperse volatiles, and reduce toxicity of the

oil to plants. However, only a small portion of the oil may be removed if significant penetration into the soil has occurred. The heat generated may cause further spreading of the oil, increasing the area of contamination and creating hydrophobic problems. Additional plant death may occur and reduce the revegetation potential. As also reported by Nyborg and McGill (1976), a tarry crust may remain after the burn which can reduce soil aeration and impede seedling growth. McGill (1976) suggests that burning should be done only where penetration of oil into the soil is slight.

Wein and Bliss (1973) stated that the increased energy adsorption on burned-over arctic soils may cause melting and the development of unstable thermokarst characteristics. According to the Concawe Secretariat (1974), incorporation of farmyard manure may be beneficial by adding microbes to soil that has been partially sterilized by burning.

A discussion of the effects of burning crude oil spills on a variety of sites in Alaska was provided by McKendrick and Mitchell (1978). Oil was applied at 10, 20 or 40 L/m^2 and burned on snow in winter, in the summer growing period, or in autumn when soils were freezing. The experiments were conducted at five sites:

1. An abandoned agricultural grass field. The oil burned easily 48 hours after application, the burn lasting 1 to 1½ hours. Winter spill was less damaging than summer spill; immediate burn of the former reduced damage substantially (Table 46.15). Most damage came from the effect of oil or burning oil and not from the burn alone. Poorest recovery in later years occurred on the summer burn. The summer burn plots also had a hydrophobic residue that may have reduced soil moisture infiltration and the spreading of grasses.
2. High brush stage in the secondary succession of an Alaskan Picea forest burned in autumn when plants were in a more resistant state and the upper soil layer was frozen. Here the oil burned well and the soil surface thawed only a few millimetres. At 4 cm the soil remained frozen until one hour after the burn started.

Table 46.15. Dry matter yields on an Alaskan agricultural grassland field in September 1973, seven months after a winter oil spill and one month after a summer oil spill as affected by burning or not burning at various times following the spill.

	Total Dry Matter g/m^2
Winter Spill	
No oil, no burn	230.0
No oil, burn only	303.8
Oiled, burn immediately	265.4
Oiled, burn delayed 1 month	159.5
Oiled, burn 48 hours	39.2
Oiled, no burn	11.2
Summer Spill	
Oiled, burned immediately	0.0
Oiled, no burn	5.2
Oiled, burn delayed	0.0
No oil, burn only	40.5

Source: Adapted from McKendrick and Mitchell (1978).

Thermokarst conditions did not develop within four years. Two-thirds of the genera were eliminated by the 20 L/m^2 application. Most resistant to oil were Equisetum arvense, Calamagrostis canadensis, Cornus canadensis, and Vaccinium uliginosum. Salix and Betula survived by stump sprouting. Vaccinium vitis-idaea and Empetrum nigrum were sensitive to damage. Other trees and moss were completely eliminated.

3. On sedge meadow where the soil was moist, oil burned rapidly but, due to moisture, the soil did not become lethally hot. Carex survival was inversely related to oil rate. It produced greater inflorescence and growth, and when burned, increased vigour one year later. Moss was eliminated and Calamagrostis canadensis survived only light oiling.
4. Spilled oil in a Picea forest was difficult to burn due to rapid adsorption of oil into the organic mat. The vegetation was very sensitive to the oil spill. Two-thirds of the genera did not survive.
5. On a wet and mesic arctic tundra, oil added while plants were actively growing resulted in drastic reduction of plant growth. Only Carex and Salix survived and oil plus burning was even more serious. No mosses or lichens survived.

McKendrick and Mitchell (1978) concluded that burning is most useful in winter when the least damage is done to vegetation, especially on grasslands and wet meadows. During the growing season, burning increases plant damage. Plant survival of burning oil is related to dormancy, reduced soil permeability to oil, high soil moisture, and low soil temperature. The authors stated that the decision to use burning as a cleanup method depends on probable increase or decrease in long term damages, risk to life and property, whether or not fire is a natural part of the ecosystem, amount of oil percolated into the soil, and probable effect on soil and surface water pollution.

46.2.2 Chemical

Chemical methods for treatment of chemical disturbance as discussed in this literature review pertain only to salt spills or particulate sulfur. Most of the papers discussed the use of divalent cations either supplied or released from compounds already in the soil to ameliorate and improve the physical condition of sodium-saturated soils.

White and DeJong (1975) discussed the chemical reclamation of brine-contaminated soils in Saskatchewan in general terms and primarily from the point of view of naturally saline soils. In employing gypsum as a calcium source to replace adsorbed sodium, one acre-foot (1.33 ha-m) of water would be required to dissolve 0.9 t of high grade gypsum. The exchange of 1 meg Na/100 g soil needs 12.49 t of gypsum per ha-m of soil. To reclaim salt-damaged soils it is necessary to reduce the electrical conductivity of the saturated extract of the soil to 4 mmhos/cm or less, to remove surface salts, prevent resalinization, replace sodium with divalent cations, and to remove contaminated groundwater by drainage. Chemical amendments may be required to neutralize pH, to react with free lime, replacing Na with Ca by using CaCl, $CaSO_4$, limestone, elemental S or H_2SO_4.

Webster (1976) stressed that no chemical treatment will neutralize the effect of brine directly and, unlike oil spills, there are no salt-decomposing organisms. He stressed the importance of converting a sodium-saturated soil to a calcium saturated soil to prevent colloidal flocculation and poor soil structure. Enrichment of the soil with calcium can be accomplished by adding $CaCl_2$, $CaSO_4$, or $CaCO_3$. Elemental S can be used to create an acidic condition, increasing the solubility of $CaCO_3$. However, elemental S should only be added where the soil is not acid and where there is an abundance of $CaCO_3$. Gypsum, however, is the most commonly used agent for soil calcium enrichment and sodium displacement.

For example, in research on reclaiming oil well salt spills in forested lands, Innes and Webster (1981) showed that while leaching with freshwater was the primary reclamation tool, liming with gypsum was necessary to displace sodium on the exchange complex which remained after extensive leaching. They limed with gypsum at 4.4 t/ha two weeks after leaching the spill. This allowed for a more rapid movement of

salts deeper into the profile in comparison to leaching without gypsum, as shown by the lower EC, Cl_2, and Na levels at depth in the gypsum treated plot (Figures 46.4, 46.5). Gypsum application also significantly reduced the SAR of the upper 30 cm of soil (Table 46.16).

In addition, concentrations of Cl_2 toxic to vegetation were significantly reduced in gypsum treated soils (Figure 46.5). Reclamation for deeper rooted vascular plants required additional gypsum liming. In contrast, other chemical treatments, including adding dolomite to the lime, sulfur, using gypsum saturated flushing water, and calcium chloride, either had little effect (e.g., dolomite) or negative effects (e.g., calcium chloride; Table 46.17).

Greenhouse experiments were performed using plastic containers 44 x 23 x 15 cm with gravel for drainage, soil, and covered with an intact segment of the forest mat. Each container contained one Ledum groenlandicum plant about 30 cm tall. Other species present included various mosses, lichens, Vaccinium vitis-idaea and V. myrtilloides. All plants were rated for performance of old and new growth and this information used to develop growth scores.

As Figures 46.4 and 46.5 and Table 46.16 indicate, although the brine and water flush plus gypsum treatment may not appear the best treatment initially, by the second year salt levels and SAR were consistently lower, especially at depth in this treatment. They are still higher than the control, indicating further reclamation is required. Thus the authors recommended an application of gypsum at 6.7 t/ha for three consecutive years.

Enviroccon Ltd. and Chemex Labs (Alberta) Ltd. (1975b) used the principle of increasing the solubility of native calcium in the soil to ameliorate salt contaminated soils in Manitoba. This was accomplished by acidification, either through applying elemental sulfur or adding ammonium salts. They pointed out that the process requires aerobic conditions. In a badly affected area where elemental sulfur or ammonium sulfate was applied at 1121 kg/ha, good reductions in electrical conductivity, sodium adsorption ratio, and exchangeable sodium were obtained with NH_4SO_4 but there was no benefit from applying elemental sulfur. In another paper by the same authors (1975a), columns of salt-contaminated soil were leached or not leached after treatment with

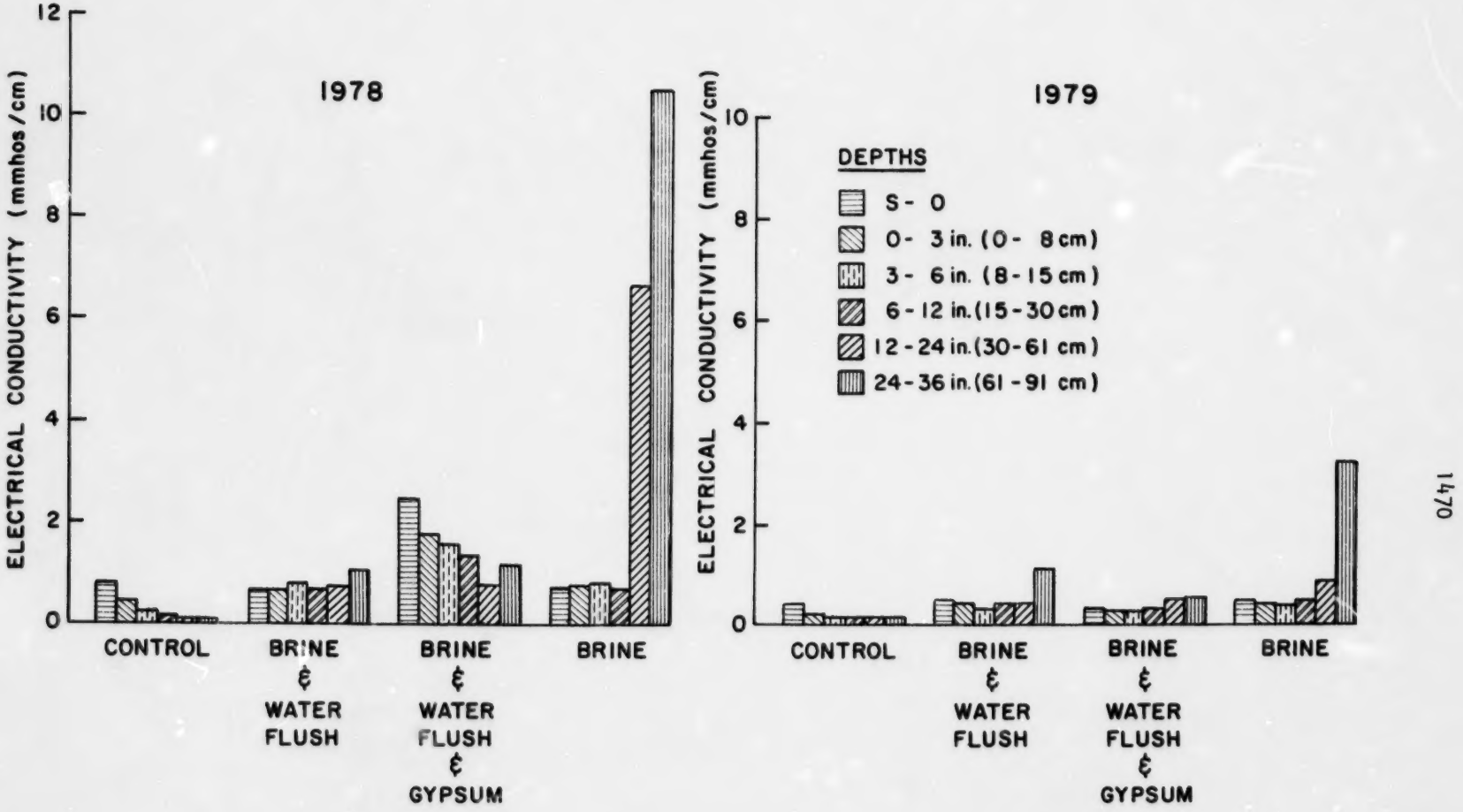

Figure 46.4. Electrical conductivity of saturation extracts for soils sampled in the fall of 1978 and 1979 at the Home Oil Battery No. 6, Swan Hills, Alberta.

Source: Innes and Webster (1981).

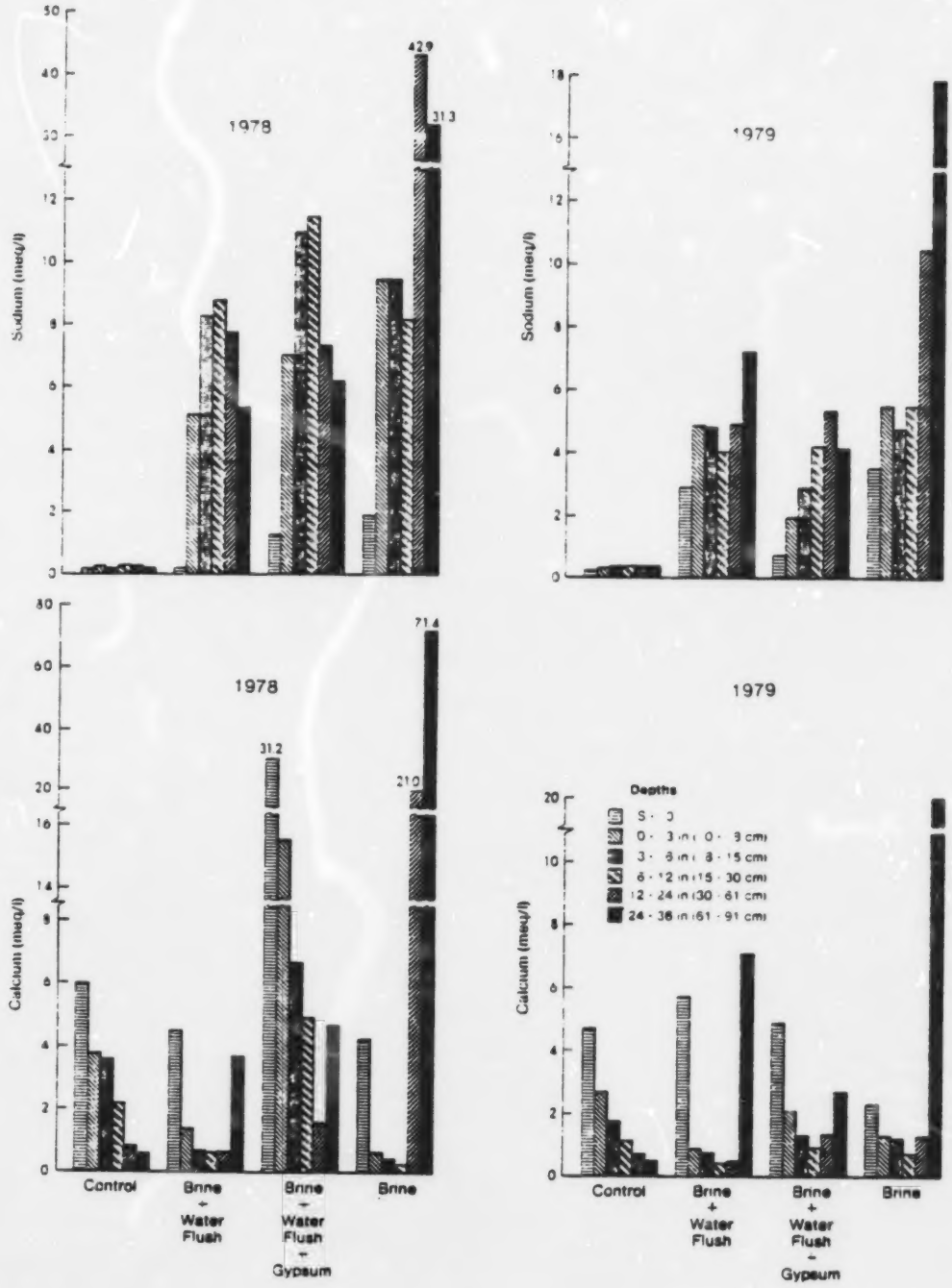

Figure 46.5. Sodium and calcium concentrations of saturation extracts for soils sampled in the fall of 1979 at the Home Oil Battery No. 6, Swan Hills, Alberta.

Source: Innes and Webster (1981)

Table 46.16. Sodium and calcium contents, and sodium adsorption ratios (SAR) of saturation extracts for two brine spill sites in Alberta; means of the top 30 cm of soil[a].

Treatments	Sodium (meq/L)		Calcium (meq/L)		S.A.R.[b]	
	1978	1979	1978	1979	1978	1979
Site 1						
control	0.23	0.24	3.88	2.58	0.15	0.19
brine & flush	6.26	4.13	1.83	1.97	5.85	3.82
brine & flush & gypsum	7.65	2.43	14.59	2.31	2.64	2.10
brine	7.20	4.80	1.42	1.39	7.58	5.27
Site 2						
control	0.97	0.23	2.63	1.64	0.75	0.22
brine & flush	4.02	1.93	1.53	1.24	4.07	2.16
brine & flush & gypsum	7.13	1.60	12.19	2.65	2.68	1.30
brine	6.84	4.16	1.01	1.12	8.17	4.99

Source: Innes and Webster (1981).

[a] The mean value for sodium, calcium, and SAR for each treatment is the means of the LFH layer, 0 to 7.6, 7.6 to 15.2, 15.2 to 30.5 cm depths combined.

[b] SAR (Sodium Adsorption Ratio) of the saturation extract was calculated using the following expression:

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$$

where the concentrations were expressed in milliequivalents per liter.

Table 46.17. Means of growth scores for two observation dates on brine spills in Alberta.

	Treatments	Means of Growth Scores[a]	
		March 30	April 30[b]
1.	control	7.6	6.1
2.	brine	2.3	2.4
3.	brine treated, water flushed, followed by restricted drainage	4.9	4.0
4.	brine treated, calcium chloride flushed, water flushed	2.1	2.4
5.	brine treated, water flushed, gypsum applied	2.3	2.8
6.	brine treated, flushed with gypsum saturated water	3.8	3.3
7.	brine treated, water flushed, gypsum-dolomite limestone applied	2.4	2.6
8.	brine treated, water flushed, sulphur applied	2.1	2.0
9.	brine treated, water flushed, gypsum applied, fertilized	3.9	3.4
10.	brine treated, water flushed, free drainage	6.2	4.9
11.	brine treated, water flushed, gypsum applied, free drainage	6.0	5.5

Source: Innes and Webster (1981).

[a] The average score for the "Old Growth" and for the "New Growth" was combined to give an aggregate score for each treatment on each of the two dates.

[b] Free drainage was imposed for treatments 1 to 9 after the first evaluation on 30 March 1978.

elemental sulfur, calcium sulfate or ammonium sulfate. Only treated soils leached well. Ammonium sulfate-treated soils had the best structure. Of the treated soils, the elemental sulfur-treated soils were the worst. Oxidation of the elemental sulfur was thought to be slow. In growth chamber tests, Avena sativa, Brassica spp., Hordeum vulgare, Medicago sativa or Triticum aestivum did not grow on the unleached soils. Growth on soils that were not treated but leached was unexpectedly good and was comparable to the treated leached soils.

In a paper of relevance to salt spill reclamation, Lagerwerff and Kemper (1975) reported on a laboratory study of methods of removing radioactive strontium from soils. Loamy sand to silt-loam soils were saturated with 95 percent Ca and 5 percent Sr and leached with 0.06 N $CaCl_2$ for varying times and rates, after which residual Sr was measured. Slow leaching with dilute calcium solution effectively removed more strontium than highly soluble salt at the surface and rapid leaching. They calculated that about 15.5 t of $CaSO_4 \cdot 2H_2O$ would be required to remove mobile Sr from 1 ha of soil with an exchange capacity of 20 meq/100 g to a depth of 60 cm.

Strosher, Younkin and Johnson (1980) contend their research, reviewed in Chapter 46.1.2, provides a structure or set of guidelines to manage sump fluid land disposal. Thus by assessing fluid chemistry it is possible to predict environmental impact. Further research, however, is needed on long term impacts, including transport and transformation. See also the discussion of salinity in Chapter 11.4.3. and sodicity in Chapter 11.4.4.

Soil pollution with sulfur dust near gas processing plants from storage piles and during handling and transportation can cause harmful acidification of the soil. Nyborg (1974) stated that sulfur applications of 4.5 to 7 t/ha can acidify most soils to the point where vegetation cannot exist. Liming can counteract the acidity. In order to calculate the lime requirement, not only must the present acidity be considered, but also the latent acidity that will develop from any unreacted elemental sulfur that may be present. Limestone must be fine (half should be less than 60 mesh), contain less than 5 percent $MgCO_3$ and be worked into the soil. The most common problems arise from strong alkalis, use of $MgCO_3$, not applying enough lime, not working the lime

deep enough into the soil, or poor soil sampling for prediction of lime requirement.

46.2.3 Leaching

Leaching is an essential part of the chemical treatment of contaminated soils. Dissolution of the chemical amendment and transport of the solution distributes it throughout the rhizosphere. However, leaching alone can sometimes carry away offending chemicals and bring about an improvement in the soil. An example of this was provided by Envirocon Ltd. and Chemex Labs (Alberta) Ltd. (1975a) where leaching without ameliorating chemicals was almost as effective in improving a salt-contaminated soil as leaching with ameliorants. Innes and Webster (1981) however, point out that the exchange complex of clay soils may still be saturated with Na after leaching has removed almost all the free salt in the soil solution.

White and DeJong (1975) pointed out the importance of leaching in connection with the use of chemical amendments for salt-contaminated soils. Drainage methods were discussed and empirical formulae were presented to predict the water needs for leaching. Rainfall is very efficient for leaching, ponding is fast but inefficient, and trickle irrigation is slow but very efficient. Fall is the best time of year for leaching due to low evaporation rates and generally low water tables. Quality of the water is important. Lagerwerff and Kemper (1975) also showed that slow leaching with dilute Ca solution had a greater ion displacing action than applying highly soluble salt at the surface and leaching rapidly. Innes and Webster (1981) reported that leaching with fresh water was the primary process for removing salt from brine spills on two forested clay rich soils in the Swan Hills area. They flushed twice, with a time interval of two to three days between flushing operations to allow salts to diffuse from micro- and mesopores into the macropores where they could be leached out by the second flush. Figure 46.6 shows the effect of flushing compared to natural leaching and the control (or non-contaminated) site. Adding gypsum or lime to the treatment did not have a large apparent effect on in situ EC or total salt measurements. However, as previously noted, it had a significant effect on adsorbed Na and ultimately on plant survival (Table 46.18).

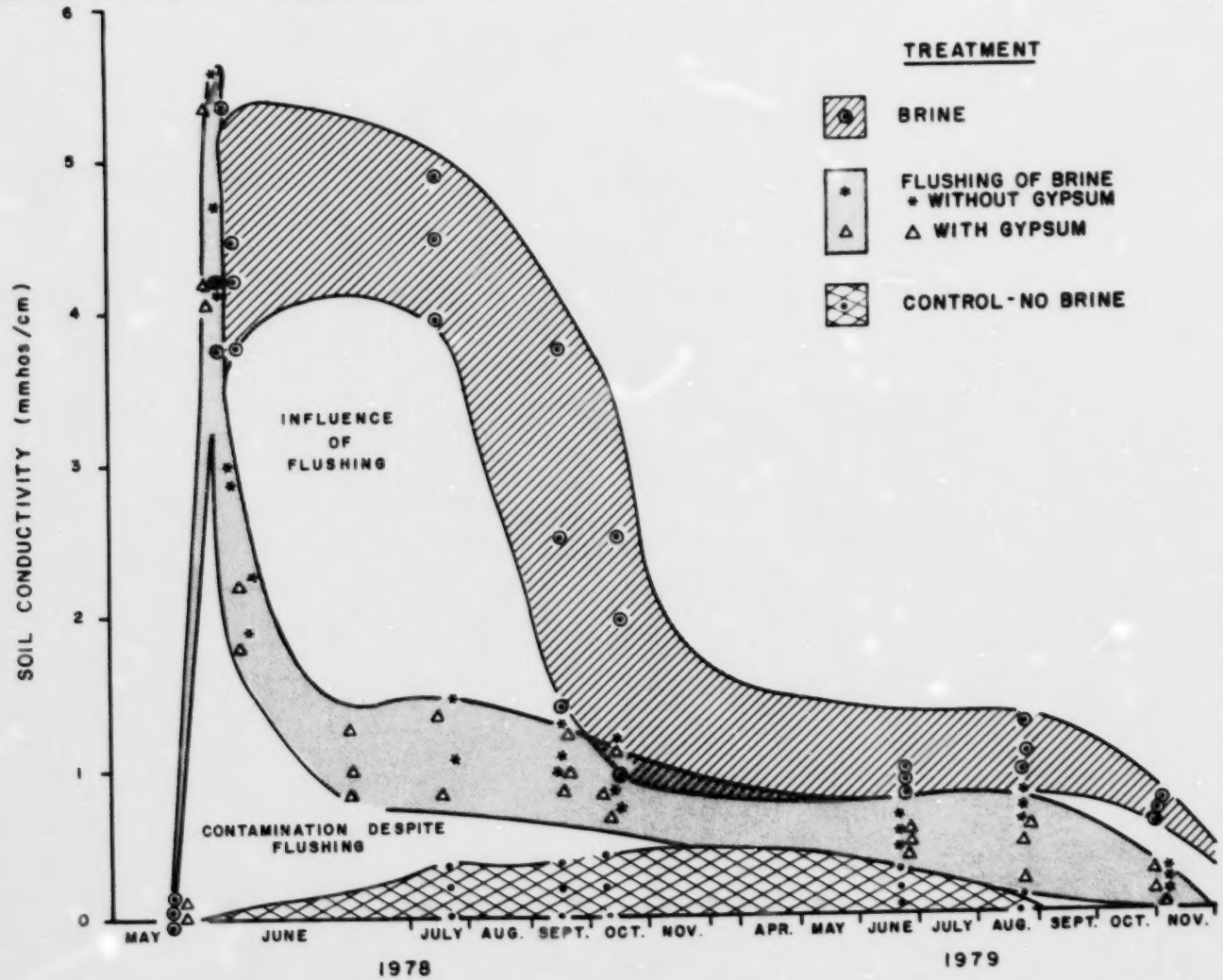

Figure 46.6. Change in total salt (soil conductivity) over time measured in situ at the Home Oil Battery No. 6, Swan Hills, as affected by treatment.

Source: Adapted from original Figure in Innes and Webster (1981)

Table 46.18. Percent dead for four species[a] of vascular plants as related to four main treatments; and the three sub treatments for two brine spill sites in Alberta, 1979.

Treatments	Mean Percent Dead
Main Treatments	
Treatment 1 (control)	7.1 a
Treatment 2 (brine + flush)	40.9 c
Treatment 3 (brine + flush + gypsum)	18.7 b
Treatment 4 (brine only)	46.6 c
Sub Treatments	
A. Control	43.9 a
B. Fertilizer + Grass - legume mixture	17.3 b
C. Fertilizer	23.7 b

Source: Innes and Webster (1981).

[a] The four species monitored were: one from Site 1, *Abies balsamea* (Balsam fir); and three from Site 2, *Ledum groenlandicum* (Labrador tea), *Vaccinium vitis-idae* (Bog cranberry), and *Vaccinium myrtilloides* (Blueberry).

Although Figure 46.6 suggests the salts will be gradually leached from the soil, eventually approaching levels in undisturbed soils regardless of treatment, damage to the vegetation is both extensive and persistent. The loss of vegetation will increase erosion potential (which is markedly significant in the Swan Hills area; Lengelle 1976) and this indirect effect will degrade soil quality. Fortunately, however, the mosses which provide erosion resistant ground cover during the crucial recovery period appear quite salt tolerant.

Two papers mentioned water movement through oil-contaminated soil in connection with rehabilitation. McGill (1976) found flushing can be effective in pushing oil to a more convenient collecting point, but care needs to be taken to ensure that this does not cause an expanded area of damage. Rowell and McGill (1978) observed that oil and water-soaked peat could be stripped from the underlying clay subsoil, windrowed, and allowed to drain so that the oil and water could be collected and pumped away.

46.2.4 Application of Reclamation Techniques in Agricultural Saline Soils to Chemically Salt Contaminated Soils

There is extensive information on reclamation of saline agricultural soils and although such reclamation is not analogous to salt spill reclamation, the reclamation techniques are somewhat similar. In saline agricultural soils salinization has generally occurred slowly over long periods of time and has resulted in a relatively stable physical-chemical soil-plant system with moderate salt levels which are spatially extensive. In salt spills, the problem occurs over a very short period of time, is usually very spatially restricted, and causes abnormally high salt levels in a soil plant system which is not in equilibrium with this salt input.

In order to reclaim saline agricultural soils the soil-plant balance must be understood. Taylor and Ashcroft (1972:452-471) have expressed the salt balance mathematically by a simple conservation of mass equation:

$$D_I C_I + S_m - D_d C_d - S_p - S_c = 0 \qquad (1)$$

where D_I is depth of irrigation water

D_d is depth of drainage water
C_i is salt concentration in irrigation water
C_d is salt concentration in drainage water
S_m is the amount of salt dissolved from soil minerals
S_p is the amount of salt precipitated
S_c is the amount of salt in harvested plants

Usually S_m, S_p, and S_c are considered negligible and equation (1) reduces to:

$$D_i C_i - D_d C_d = 0 \tag{2}$$

or

$$\frac{D_d}{D_i} = \frac{C_i}{C_d} = \frac{EC_i}{EC_d} \tag{3}$$

where EC_i is electrical conductivity of the irrigation water
EC_d is electrical conductivity of the drainage water

To use equation (3) a maximum permissible salt concentration in the rhizosphere, based on crop salt tolerance, is selected and substituted into (2) as C_d. Then C_i is measured and D_d/D_i is calculated. Equation (3) is limited by nonuniform salt distribution down the profile and between macro-, meso-, and micropores, the effects of S_m, S_p and evapotranspiration (E_t) and infiltration (I_t).

Including a term for evapotranspiration and expressing the quantity of water required as a leaching requirement (LR) or leaching fraction (LF) the depth of irrigation water can be expressed as:

$$D_i = \frac{E_t}{1-LR} \tag{4}$$

$$\text{where } LR = \frac{D_d}{D_i} \qquad \text{or } LF = \frac{D_d}{D_i} \tag{5}$$

(Note: LF and LR are not identical although they are very similar. See Taylor and Ashcroft [1972:452-465] for an explanation.)

Expanding the approach to account for infiltration

$$D_d = D_i - D_e \tag{6}$$

where D_e is the equivalent depth of water evapotranspired.

Also

$$D_i = It_i \tag{7}$$

and

$$D_e = E_t t_c \tag{8}$$

where It_i is the infiltration rate in mm over the infiltration time, t_i, and the irrigation cycle, t_c, in 24 hr days. $E_t t_c$ is the evapotranspiration rate in mm over the infiltration time, t_i, and the irrigation cycle t_c in 24 hr days.

Substituting D_d from equation (6) into (5) yields

$$LF = \frac{D_i - D_e}{D_i} = 1 - \frac{D_e}{D_i} \tag{9}$$

Substituting D_i from (6) and D_e from (7) yields

$$LF = \frac{E_t t_c}{It_i} \tag{10}$$

where $E_t t_c / It_i$ reduces to a dimensionless ratio.

When drainage is limiting

$$Ot_c \quad (It_i - E_t t_c) \tag{11}$$

where $Ot_c = D_d$ and O is the average drainage rate in mm/d past the lower boundary of the root zone.

therefore

$$LF = \frac{Ot_c}{E_t t_c + Ot_c} = \frac{O}{E_t + O} \qquad (12)$$

Equation (12) defines LF when drainage is limiting and when drainage is not limiting equation (10) defines LF.

Once the quantity of irrigation water is calculated as LF from (10) or (12) its required quality is calculated by substituting (3) into (5b) as follows:

$$LF = \frac{EC_i}{EC_d} \qquad (13)$$

Combined with a knowledge of crop salt tolerance measured against EC these equations then can be used to specify the quantity and quality of irrigation water needed to reclaim agricultural saline soils by leaching.

It is also possible, and necessary in highly sodic soils, to reclaim salt rich soils by liming in addition to leaching. Bolt and Bruggenwert (1976:187) present a simple mathematical procedure for calculating the quantity of gypsum required as follows:

The required quantity of gypsum per unit of irrigation water is

$$SAR = \frac{c_{i,+}}{\sqrt{(c_{i,2+} + x_i)/2}} \qquad (14)$$

where SAR is the sodium adsorption ratio

$c_{i,+}$ is the original concentration of the monovalent cation in the irrigation water

$c_{i,2+}$ is the original concentration of the divalent cation in the irrigation water

x_i is the quantity of gypsum required per unit volume of soil.

Using the crop rooting depth as Dd then the total quantity of gypsum can be calculated as

$$x_{i...d} = (ESP_i - ESP_f) \times CEC \times \rho b \times D_d \qquad (15)$$

where ESP_i is the initial ESP of unreclaimed soil

ESP_f is the final ESP of unreclaimed soil.

The required depth of irrigation water, D_i, is calculated from:

$$D_i = \frac{x_{i...d} \times 10}{C_{i,2+} + x_i} \qquad (16)$$

(Note: the d is multiplied by 10 to give D_i in mm. See Bolt and Bruggenwert for details of units of measurement).

Therefore

$$x_{i...d} \simeq D_i \cdot x_i \qquad (17)$$

Thus both the quantity of irrigation water and the quantity of gypsum required can be estimated.

When salinization is caused by low rates of infiltration, permeability, or high water tables in arid areas, artificial drainage may ameliorate the salinity. Also saline soils can often not be irrigated without intensifying salinization or sodification unless they are simultaneously artificially drained. Eggelsmann (1978) presents the mathematical techniques to calculate drain spacing in saline soils.

When impermeable strata exist only at depths 2 m below the drain the following formula applies:

$$a = \frac{10 \cdot k \cdot D \cdot t}{v \cdot \ln\left\{1.16\left(\frac{h_o}{h_t}\right)\right\}} \qquad (18)$$

where a is drain spacing in m

K is conductivity in cm/d

D is distance from impermeable layer to drain in m

V is volume of coarse pores (i.e., air filled porosity at field capacity - a dimensionless fraction)

h_o is maximum initial height of water table above the drain

h_t is maximum final height of water table above the drain.

The volume of coarse pores is estimated from conductivity as follows:

$$V = (\sqrt{K}\ ) \times 0.01 \qquad (19)$$

If the impermeable layer is within 2 m of the drain, but not above the drain, drain spacing can be calculated as follows:

$$a = \frac{4.5 \cdot t \cdot k \cdot h_o \cdot h_t}{V\,(h_o - h_t)} \qquad (20)$$

Equation (19) is used to calculate V.

Thus there exists well developed mathematical approaches to reclaiming saline soils by leaching, liming, and drainage. As was mentioned initially, extrapolation of this approach to reclamation of artificially salt contaminated soil is limited by the following reasons:

1. the lack of data on salt tolerance to very high salt levels over short periods of time;
2. the lack of data on natural species tolerance for application in the Green Area of Alberta, all the mathematical approaches require salt tolerances to be given;
3. these approaches are cost effective for spatially and temporally distributed low salt levels, not necessarily for spatially and temporally restricted high salt levels; and

4. the equations are intended to apply to large time and space continuums.

Research is, then, needed on salt tolerances to peak stresses and on native species. Secondly the equations must be modified or adapted to more transient peak phenomena.

46.2.5 Biological

Cook and Westlake (1973) presented a chart showing the various processes by which oil is lost from the soil (Figure 46.7). McGill (1977) stated that initially, volatilization accounts for 20 to 40 percent of the losses of spilled oil. Photo-oxidation accounts for a small loss. Natural weathering leads to chemical alterations and possibly to a tarry crust formation. The remaining losses are due to biological decomposition but the need for a microbial inoculant is very limited, for example only on very sandy, acidic soils or on very acid peats. The literature indicates that micro-organisms capable of degrading petroleum are widely found in nature. MacKay and Harrison (1973), in reviewing the proceedings of a conference on oil and the Canadian environment, stated that bacteria capable of degrading oil are ubiquitous in the north-west Atlantic and adjacent coastal areas and inoculation is not necessary. Organisms capable of degrading crude oil included Achromobacter, Streptomyces, Corynebacterium, Pseudomonas, gram possitive cocci, Micrococcus, Bacillus, Flavobacterium, Cytophaga, Penicillium, Paecilomyces, and Verticillium mortierella. Generally fungi used the entire range of the N-paraffins while bacteria were more restricted in their substrate range (Gossen and Parkinson 1974).

Hunt (1972) reviewed literature on the microbiology of terrestrial crude oil degradation, particularly as related to Arctic conditions. Oil spills supply a great amount of decomposable carbon. Bacteria decompose oil more rapidly than fungi or actinomycetes but are generally less efficient users of acids, alcohols, and ketones. Fungi can use these, so a large mixed population develops. The limiting factors are the supply of nitrogen and phosphorus. Oxygen is needed for decomposition and it is important to note that oxygen diffusion is slower in oil than in water. Under arctic (Alaska) conditions biological decomposition of an oil spill may take 15 to 20 years.

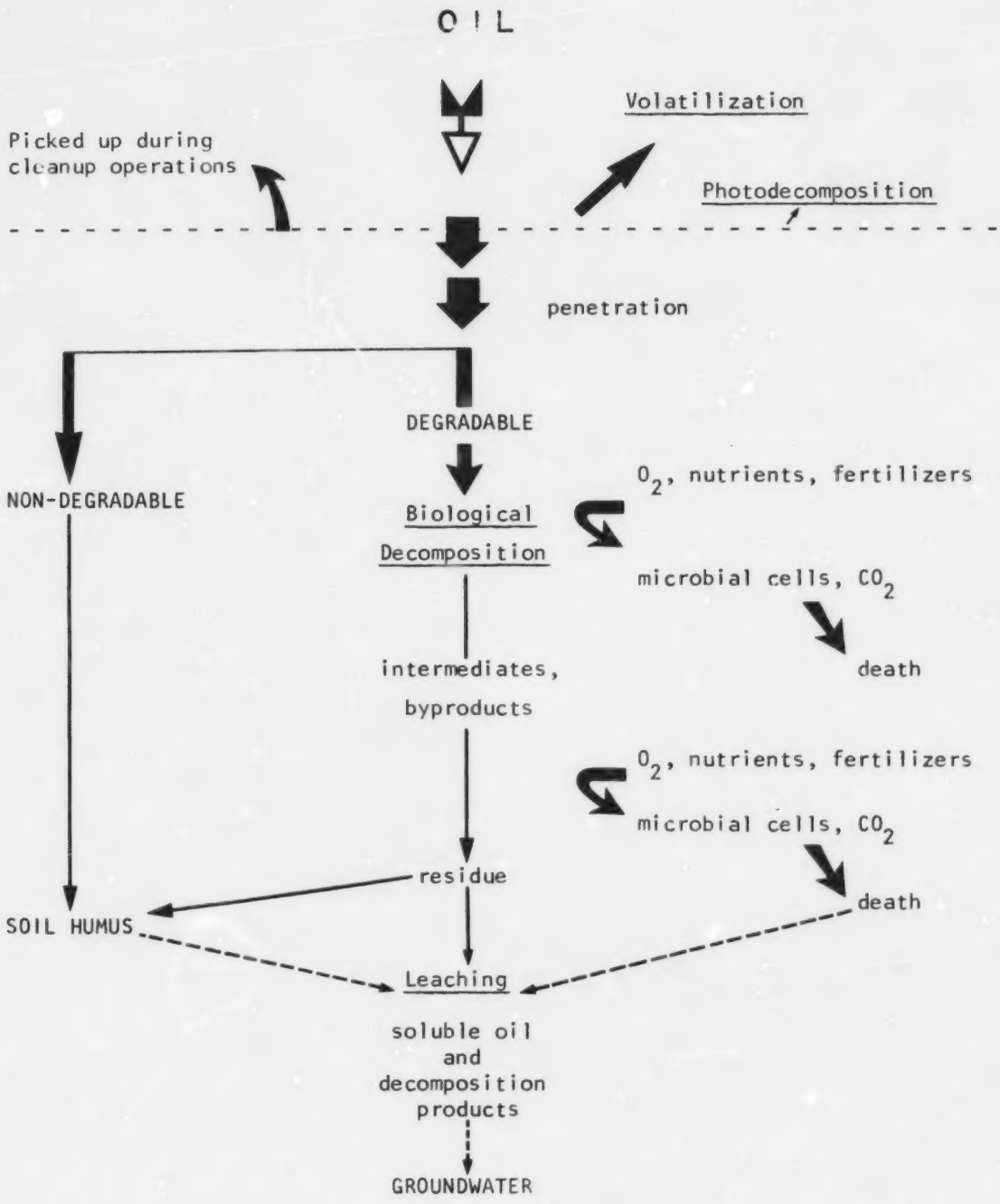

Figure 46.7. Pathways for loss of oil from soil.

Source: Cook and Westlake (1973)

McGill et al. (1974) indicated that the oil content of soil can be reduced by volatilization, burning, and biological oxidation. The balance between bacteria and fungi depends on pH and aeration. Possible side effects in reclamation are reduction of pH, increased soluble salts, and build-up of anaerobic organisms. Possible benefits are increased fertility and nitrogen fixation.

Conversely, Innes and Webster (1981) pointed out that increased microbiological activity may cause a decreased plant nitrogen availability, since plants compete less effectively for soil N than, for example, soil bacteria.

In field trials in Alaska, Gossen and Parkinson (1974) found an initial decline in microbial activity, taken to be a period of adaption, followed by an increase in numbers. Little decomposition could be detected in the field by gas chromatography after 14 months but in 34 months the entire range of N-paraffins had been lost.

Westlake et al. (1974) emphasized that each crude oil is unique but those with a moderate N-saturated content behave rather similarly and are easily degradable. Atypical oils, such as those largely lacking in N-saturated fraction, react differently. Mesophylic organisms cultured at 30°C are not capable of the same growth at low temperatures as those previously cultured in the presence of oil at low temperatures (e.g., 4°C). Isolates enriched from a low quality oil (low in aromatics) can readily metabolize a higher grade oil containing more aromatics and N-saturates thougn those organisms enriched from a high grade oil are less able to use the low grade oil.

Growth and isolation of micro-organisms growing on crude oil was studied by Jobson, Cook and Westlake (1972). Microbial growth is typified by emulsification of the petroleum, an increase in bacterial numbers, and an increase in specific gravity of the residual oil. Pseudomonas, Flavobacterium, and Achromobacter were the most common genera isolated. The short chain saturates (C_{16} to C_{25}) were utilized first (Figure 46.8). The use of inoculants to deal with oil spills will depend on whether the mixture contains organisms capable of utilizing the oils of lowest quality in the spill. Residual materials left in the soil after metabolism of the oil by microbes under normal conditions are similar to the regular soil humic matter.

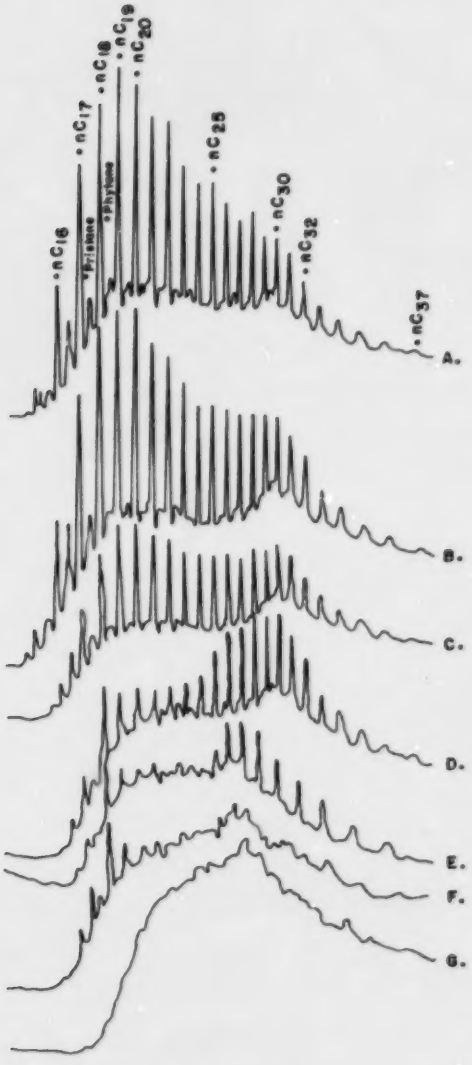

Figure 46.8. Gas-liquid chromatographic analysis of residual saturate fractions from sequential utilization of oil by mixed population at 30C. (A) Saturate fraction of control North Cantal oil. (B) Residual saturates after 2 days of incubation. (C) Residual saturates after 3 days of incubation. (D) Residual saturates after 4 days of incubation. (E) Residual saturates after 5 days of incubation. (F) Residual saturates after 14 days of incubation. (G) Residual saturates after 21 days of incubation.

Source: Jobson, Cook and Westlake (1972)

Parkinson (1973) studied two simulated oil spills on Arctic soils. Norman Wells crude was applied at 1 to 1.5 cm depth. Degradation of the oil involved microbial use of the N-paraffin fraction but the rates were slow. After one month, respiration rate was in most cases doubled by fertilizer treatment of the spill (Table 46.19). Fertilizer gave a large increase in N-paraffin degradation.

On an unused, overgrown airstrip in the Swan Hills, Jobson, Laughlin and Westlake (1974) added oil at 60 L per 9 m^2 plot with or without urea-phosphate fertilizer (27-27-0) and with or without microbial inoculum at 10^6 cells per cm^2. There were no significant changes in soil pH, which was 4.8 to 5.9. There was a significant increase in bacterial numbers within 12 days after application of oil plus fertilizer. This stimulation decreased within 66 days (Table 46.20). After 66 and 308 days the N-saturated fraction was reduced where fertilizer had been applied as compared to plots where fertilizer had not been applied (Figure 46.9).

Westlake, Jobson and Cook (1978) reported on a study at Norman Wells, N.W.T. that was similar to the one above. The soil was analyzed 0, 22, 321, 416, 687, and 1059 days after oil application on bush plots and cleared (cutline) plots. After 22 days there were no differences in bacterial numbers in the control, oiled, and oiled plus bacteria treatments, but where fertilizers were added, all the oiled treatments contained much larger numbers of bacteria (Figure 46.10).

Gas chromatography indicated that N-saturates were decomposed in 22 days in fertilized plots but were attacked more slowly where fertilizer had not been applied. Addition of bacterial inoculum did not improve the rate of oil decomposition.

Regarding the microbial aspects of the extensive study edited by Toogood (1977) on the agronomic management of oil-contaminated soil, measurements 3 to 10 months after oil was added showed that bacterial population was stimulated only if fertilizer was used. Maximum increases of 35- to 65-fold were then recorded. Bacteria were more stimulated than fungi and the saturated fraction in oil was totally degraded with the exception of the branched chain molecules, pristane and phytane.

Table 46.19. Effect of temperature and fertilization on soil respiration rate at two arctic sites.

Site	Treatment	Respiration Rate ul O_2 g^{-1} $6hr^{-1}$ Temperature 0°C	10°C	20°C
Tuktoyaktuk	control (no oil)	90.7	204.8	497.1
	non fertilized	52.2	157.5	382.9
	fertilized N & P	67.2	293.4	803.5
Tununuk	control (no oil)	72.5	105.9	219.2
	non fertilized	34.5	99.5	248.4
	fertilized N & P	103.9	288.4	573.7

Source: Parkinson (1973).

Table 46.20. Bacterial counts of Swan Hill oil spill plots.

Treatment	Bacterial count X 10^6/g after[a] 12 days	66 days	308 days
Control	13.5	56.7	41.7
Plus oil	59.5	281.5	60.1
Plus oil and bacteria	77.0	312.5	47.5
Plus oil and urea-phosphate	5162.5[b]	574.5[b]	680.0[b]
Plus oil, bacteria and urea-phosphate	3753.3[b]	1710.0[b]	525.0[b]

Source: Jobson, Laughlin and Westlake (1974).
[a] All counts are the mean values from quadruplicate plot counts.
[b] Significantly different from the oil treatment values at the 95% confidence level.

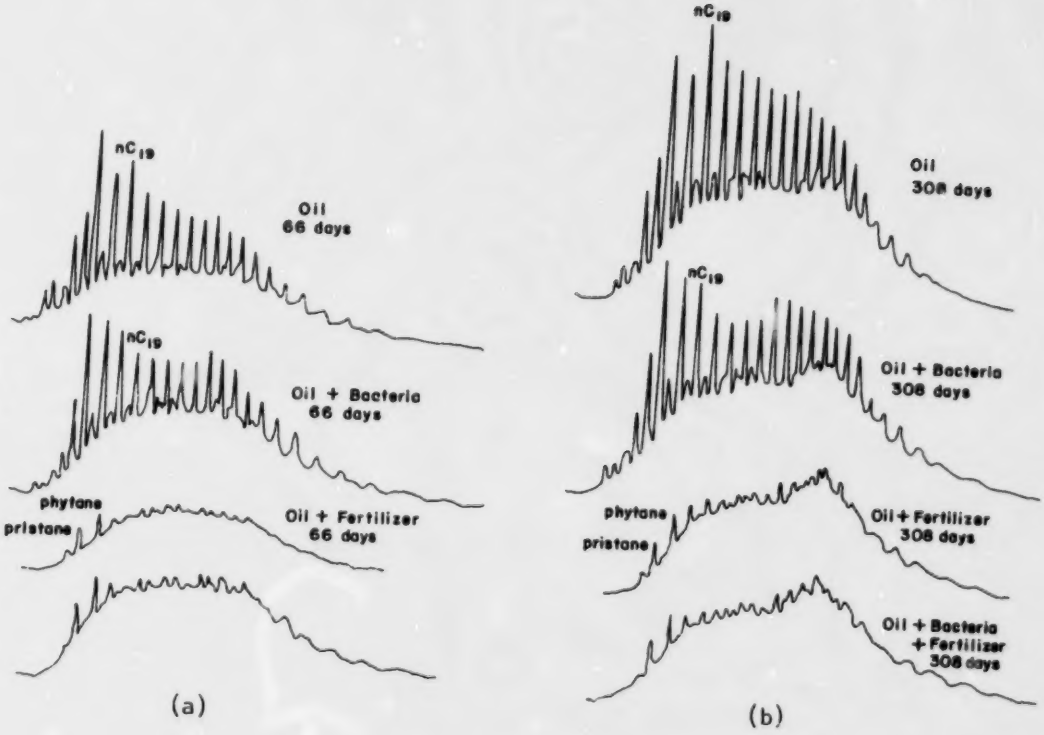

Figure 46.9. Gas chromatographic profiles of the N-saturated fraction of the Swan Hills oil (a) 66 and (b) 308 days after contact with the soil and various amendments.

Source: Jobson et al. (1974)

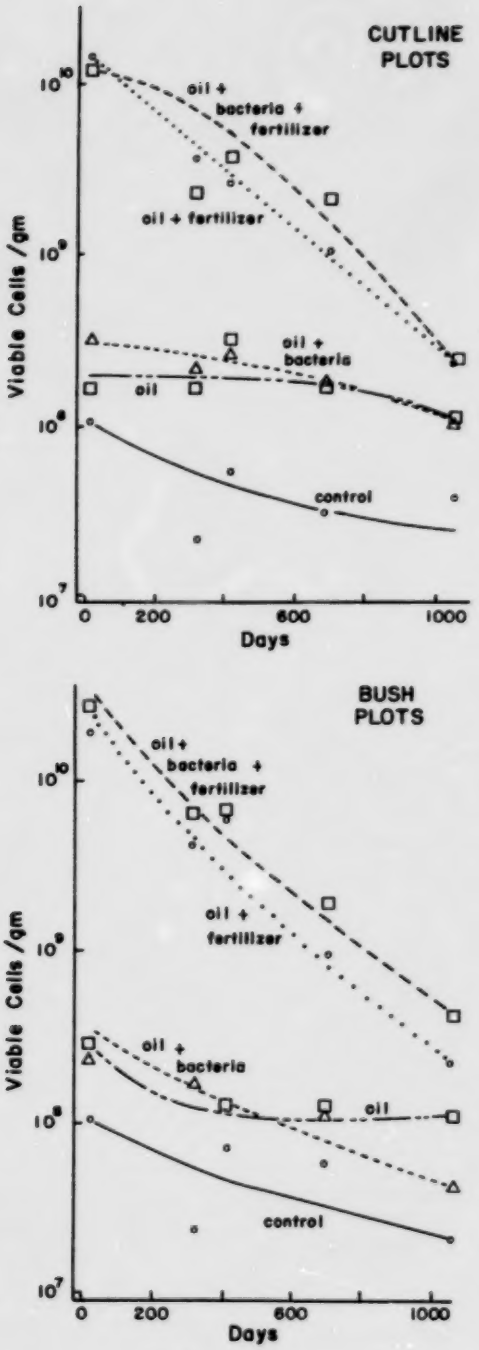

Figure 46.10. Changes in bacterial count in experimental oil spill plots at Norman Wells, Northwest Territories, in relation to inoculation and applied fertilizer.

Source: Westlake, Jobson and Cook (1978)

Westlake et al. (1976) compared the biodegradation of shale oils with that of crude oils. Shale oils require hydrogenation before commercial use. In testing with microbial enrichment it was found that hydrogenated shale oils supported abundant microbial growth and a 20% reduction in saturate content was achieved. With raw shale oil only a 5% reduction in saturate content was achieved. It was concluded that hydrogenation should be done at the oil extraction site prior to transport of the oil. If a transportation accident should occur, a more biodegradable product would be spilled.

The Prairie Regional Oil Spill Containments and Recovery Advisory Committee (1976b) published summaries of 35 papers and articles on microbial decomposition of oil. Some of these may be applicable to conditions in Alberta.

46.2.6 Cultivation

Several papers mentioned the necessity for aerobic conditions for decomposition of oil in soil. McGill (1976, 1977) emphasized the value of cultivation for aeration, breaking crusts, or enhancing volatilization. But cultivation must not be so deep as to bury oil-contaminated soil and reduce decomposition.

Rowell and McGill (1978) discussed a reclamation method used on an oil spill on a wet Picea mariana muskeg. The water- and oil-soaked peat was stripped down to the underlying clay subsoil and piled in large windrows. This enabled the water and oil to drain from the peat, be collected, and pumped from the site. When the oil content was low enough, the surface layers of the windrows were spread back on the subsoil. However, initial attempts to do this were not very successful. Oil distribution was very uneven and poor growth was generally related to high residual oil levels.

The Concawe Secretariat (1974), in discussing cleanup of soil after an oil spill, stated that aeration by tilling, particularly during warm weather, is important. The operation should be shallow, such as discing or harrowing, to keep the oil near the surface, although deeper oil contamination may require plowing or chiselling.

In comprehensive studies at Ellerslie and Redwater, Alberta on Black Chernozemic soils, Toogood (1977) reported that cultivation is

necessary along with fertilizers for oil decomposition. But intensive cultivation (more frequent operations than normal) was not found to be better than normal cultivation. The maximum rate of oil decomposition in central Alberta was about 150 kg of oil carbon per hectare per day or about 7 kg of oil/m^2/a. Decomposition was much faster in the first year than in the second year. The rate of decline of the oil content of soil and the effect of fertilization at the Ellerslie and Redwater plots is indicated in Table 46.21. The effects of fertilization, and cultivation, and their interactions are shown in Figure 46.11.

According to Rowell and McGill (1978) an old spill on Grey (Luvisolic) soil in the Swan Hills supported a limited growth of grasses and legumes in the first year of seeding only where the crust had been broken by raking. The oil contents of the 0 to 2.5 cm depth and the 2.5 cm to 15 cm depth without raking were 16.3 and 1.2 kg/m^2, and with raking were 12.5 and 2.2 kg/m^2 respectively. At an oil spill site at Leedale, Alberta, the effect of tillage alone or together with fertilizer and lime was to enhance the decomposition of the oil (Table 46.22).

Wein and Bliss (1973) warned that cultivating oil contaminated soils in the Arctic (as with burning or ditching) is liable to create thermokarst conditions.

Cultivation is also useful in some situations to help restore or rehabilitate lands contaminated with salt. Here, the objective is to incorporate amendments or to bring naturally-occurring amending materials into play to ameliorate or correct the offending condition. Webster (1976) suggested, that in reclaiming salt spills, tillage to incorporate amendments should be as shallow as possible. Deep plowing may be used to bring calcium salts from lower depth to be mixed with the upper parts of the solum.

White and DeJong (1975) found reclamation of salt-affected soils entails improvement of soil structure, permeability, drainage, leaching, and lowered water tables. This may involve deep plowing, subsoiling, or chiselling.

Burial of offending material, which in a sense is related to cultivation, is a reclamation measure that can be applied to some soil contaminants. Graveland (1974) studied burial as a means of dealing

Table 46.21. Oil content of soils at the Redwater and Ellerslie, Alberta plots following oil spills (kg/m²; 0-30 cm depth).

At Ellerslie Plots. (Oil spilled 17-20 July 1973)

Oil Tr.	Sub-plots	Initial Content[a]	Date of Sampling: 1973 31 Aug.	1974 25 June	1974 27 Oct.	1975 23 July	1977 25 July
2(light)	NF[b]	5.5	4.2	2.5	1.8	1.5	1.3
	F	5.5	3.2	1.6	2.1	1.4	1.3
3(medium)	NF	13.7	10.4	10.6	8.6	4.0	4.4
	F	13.7	11.1	6.5	5.9	4.3	3.9
4(heavy)	NF	24.9	17.3	12.7	12.4	7.6	6.9
	F	24.9	17.2	10.4	9.6	8.1	6.6

At Redwater Plots. (Oil spilled 21 June - 4 July 1973)

Oil Tr.	Sub-plots	Initial Content[a]	Date of Sampling: 1973 23 Aug.	1974 26 June	1974 26 Oct.	1975 24 July	1977 25 July
2(light)	NF	5.5	2.9	1.4	1.8	1.4	1.2
	F	5.5	2.0	0.7	1.1	0.9	0.9
3(medium)	NF	13.7	9.4	7.1	7.8	3.6	4.6
	F	13.7	8.2	5.8	5.2	3.6	3.7
4(heavy)	NF	24.9	13.4	9.4	9.8	7.4	7.1
	F	24.9	11.0	8.7	8.2	7.0	6.0

Source: Toogood ed. (1977).

[a] By calculation, assuming all oil retained in 30 cm depth

[b] NF = no fertilizer, (3 plots), F = fertilized (4 plots).

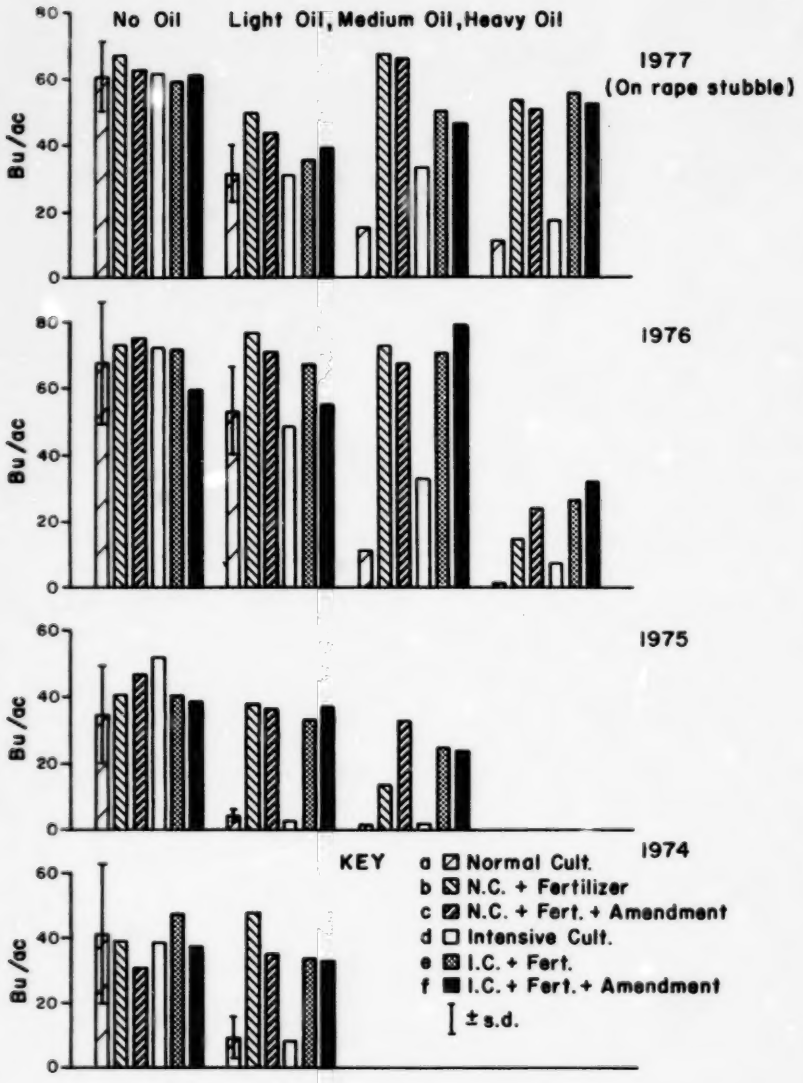

Figure 46.11. Barley yields on a Black Chernozem soil at Redwater, Alberta, contaminated with oil at 5.54 kg/m^2 (light), 13.7 kg/m^2 (medium) or 24.9 kg/m^2 (heavy) in 1973.

Source: Toogood ed. (1977)

Table 46.22. Oil content of the soil at two depths at the Leedale, Alberta oil spill study site in September 1976 as affected by tillage, fertilizer and lime treatment.

Treatment			Oil Content kg/m^2	
Tillage	Fertilizer	Lime	0 to 4 cm	4 to 15 cm
no	no	no	7.9	2.7
yes	no	no	5.8	1.8
no	yes	no	1.4	1.8
yes	yes	no	2.1	2.9
no	yes	yes	5.8	0.8
yes	yes	yes	1.8	3.3

Source: Adapted from Rowell and McGill (1978).

with particulate sulfur spills. The work was done in the laboratory using soil columns. Elemental sulfur, clean or "dirty", was sandwiched between layers of lime-rich subsoil and then the columns were leached with water. As sulfuric acid was produced, it was neutralized by the lime to produce gypsum. The authors concluded that burial of sulfur spills in calcareous soils is an easy and feasible method of reclamation.

46.2.7 Fertilization

Almost all references to the use of fertilizers in treatment, restoration, and rehabilitation of chemical disturbances on land were in connection with oil spills. Nearly all papers indicated a need for fertilizers in rapid and satisfactory rehabilitation of oil-contaminated soil. One exception, Sexstone et al. (1978), considered fertilization not applicable in the far north. Cook and Westlake (1973) suggested that the addition of fertilizers may increase the toxic effect of the oil in forest soils.

As pointed out by Rowell (1977) and others, biological decomposition of oil requires adequate elemental nutrition. He suggested that the added nutrients N, P, K, and S should be in the ratio 10:4:10:1. Biological activity in the soil is stimulated by the addition of oil. McGill (1977) stated that soil microbes compete aggressively with vascular plants for nutrition. Therefore the elements of plant nutrition need to be in adequate supply for both the microflora and the higher plants. Thus, as the native fertility of soils becomes less, the need for fertilizers becomes greater when reclamation is attempted after an oil spill. The amounts of fertilizer required may be very substantial. Nyborg et al. (1974), in discussing oil spill reclamation research in the Swan Hills-Slave Lake areas suggested that 785 kg N, 224 kg P, 303 kg K, and 40 kg S per hectare should be applied.

McGill et al. (1974) found that nitrate nitrogen was more effective in promoting oil decomposition than urea nitrogen or ammonium nitrogen. Potassium nitrate was better than calcium nitrate, possibly because of the nutrient effect of the potassium or the production of soluble potassium organic salts which were made more soluble and more available for continued microbial decomposition.

Respiration of soil (production of CO_2 and consumption of O_2) increases when oil is added due to partial conversion of oil carbon to CO_2. Addition of nutrients may increase the respiration rate five to ten times (Figure 46.12).

McGill and Nyborg (1974) noted the rate of oil decomposition was most rapid and complete when soil was mixed, drained, and nutrients added. The form of nitrogen affected the rate of nitrogen use. Ammonium persisted longer than nitrate, probably because of differences in mobility, denitrification, and preferred use of nitrate by microbes, and mineralization. Plant germination and growth did not occur unless the soil was drained and germination was enhanced by treatments which resulted in highest losses of oil.

Rowell and McGill (1978) reported on attempts to rehabilitate an oil spill on a mixed area of peat and Dark Grey (Luvisolic) soils. Movement of the growth front of native grasses and sedges onto the old spill (about four years) was about 1 m/a. This could be accelerated by fertilization. In the same paper, they reported on the use of windrows constructed of the oil- and water-soaked peat to allow drainage and disposal of the oil and water. Fertilizer placed in planting holes drilled deep in the windrows could be detected by chloride analyses to have been transported in solution to at least 30 cm from the point of application.

Toogood (1977) edited a report of comprehensive studies of the effect of oil spillage on agricultural Black Chernozemic soils. Basically, the treatments were no oil and oil at 5.5, 13.7, and 24.9 kg/m^2. The plots were not fertilized or N P K S fertilizer was applied at rates of 10:3.1:2:1 in 1973 and 10:2:2.5:1 in 1974 and onwards. Amounts per hectare depended on soil tests. Normal fertilizer additions were applied to all plots at seeding time.

With added fertilizer and normal tillage, crop yields returned to normal after one year at the light oiling rate, to 90 percent of normal in two years at the medium oiling rate, and to 70 percent of normal after three years at the heavy rate of oiling. A report by the Concawe Secretariat (1974) indicated that most spills can be reclaimed in two to four years with proper aeration and fertility.

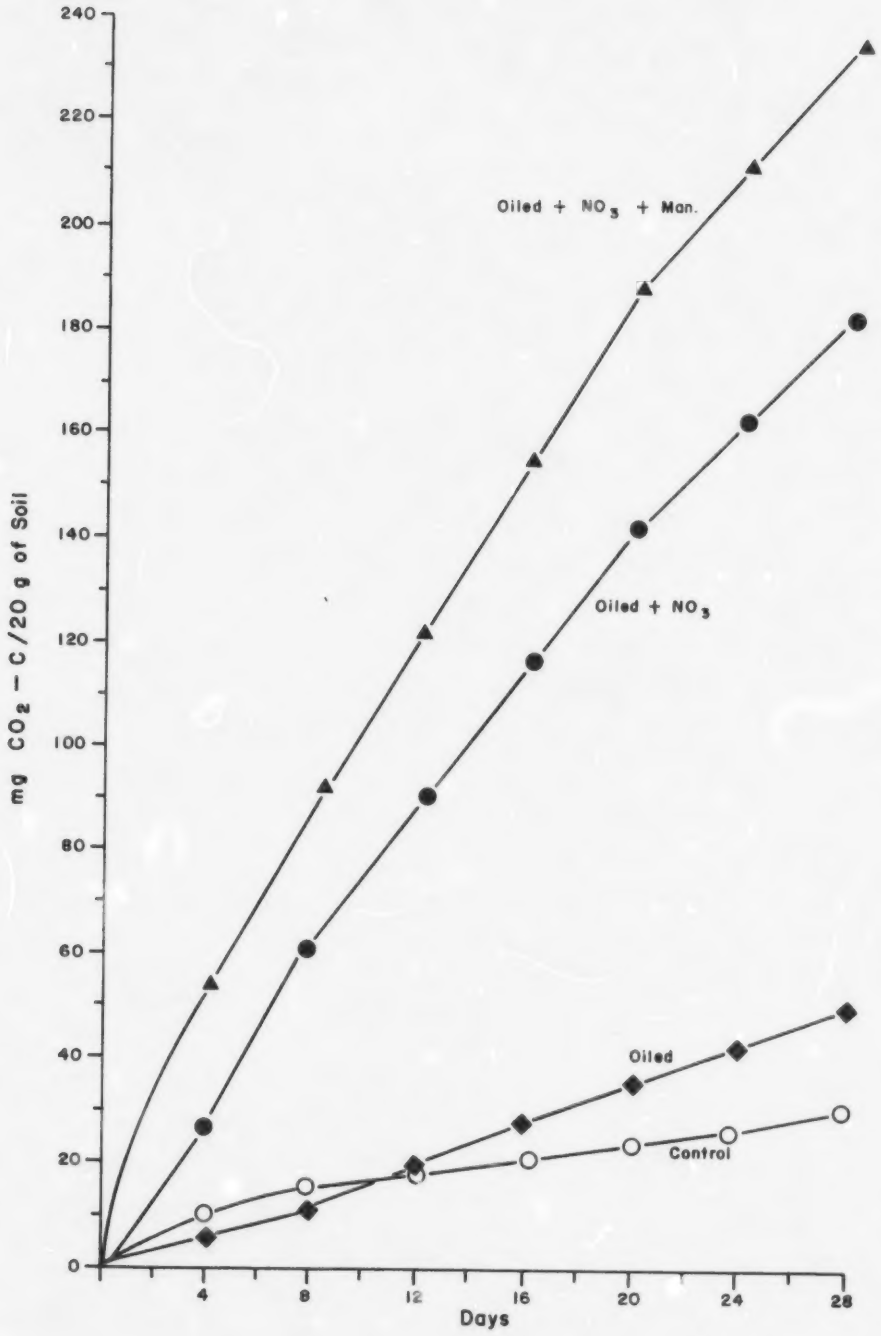

Figure 46.12. CO_2 production by Angus Ridge soil as affected by the presence of oil and added nutrients. Original oil content = 13%.

Source: McGill et al. (1974)

In the studies reported by Toogood (1977), stimulation of the bacterial population (35- to 65-fold) resulted from the application of oil and fertilizer. Where fertilizer was added, the saturate fraction of the oil was totally degraded with the exception of the branched-chain molecules, pristane and phytane. The effects of different amounts and grades of oil on the amount of fertilizer nitrogen required for the shortest-term decomposition were derived from the experimental data and are presented in Figure 46.13. The effects of different rates of spill on soils of varying native-nitrogen content on the amount of fertilizer nitrogen required to decompose a light crude oil are shown in Figure 46.14.

On oil spills in the Swan Hills-Slave Lake areas and in Black Chernozemic soils, Nyborg et al. (1974) observed that lack of vegetation or poor growth is due primarily to waterlogging, poor physical conditions, and nutrient deficiencies, rather than to toxicity of the crude oil. In the field experiments at Swan Hills, oil-contaminated soil was drained or not drained, treated or not treated with fertilizer and amendments (lime, black soil as inoculum, and micronutrients), and mixed or not mixed. The results showed that drainage and fertilizers were necessary for satisfactory germination of Avena sativa (Table 46.23). Amendments greatly increased plant growth compared with no amendments added to the fertilizer. Fertilizing substantially reduced the oil content of the soil.

Greenhouse experiments by Nyborg et al. (1974) indicated that the high rates of fertilizer that are needed to overcome the infertility of oil-contaminated soils may lower pH to a level that is injurious to some acid-sensitive crops such as Hordeum vulgare or Medicago sativa. Experiments with seedlings of Picea mariana, P. glauca, Larix laricina, Cornus sp. and Salix sp. indicated that on two peat soils containing 60 and 103 percent crude oil by weight, damage was severe but the trees did survive the two-month experiment. In three Black Chernozemic agricultural soils, heavy rates of fertilizer (785 kg N, 224 kg P, 303 kg K, and 40 kg S per hectare) would sustain plant growth on oiled soils and result in rapid decomposition of oil. A 50 percent reduction in oil content was obtained in five months. Oiled soils did not take up

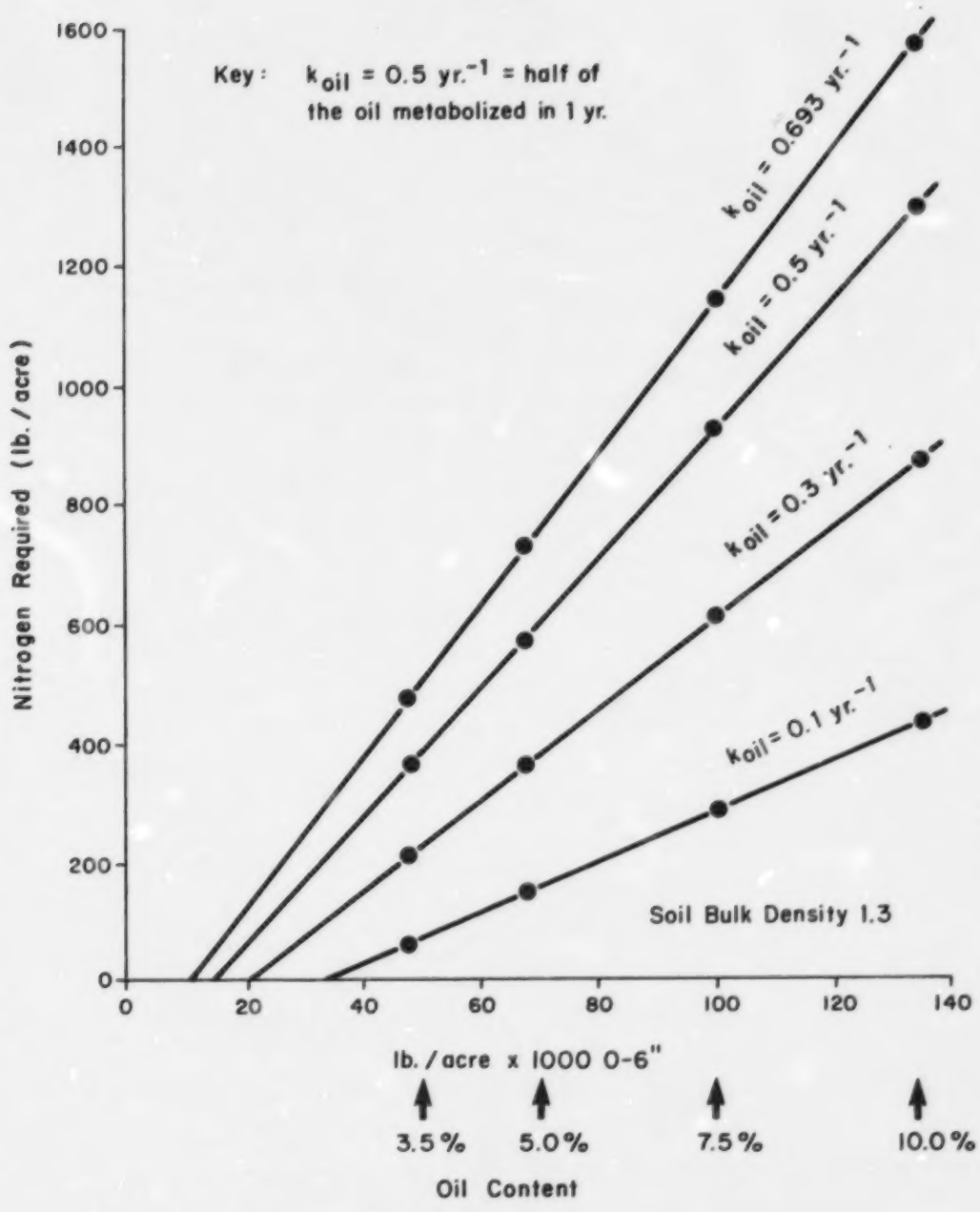

Figure 46.13. Theoretical effects of decomposition rates of different oils on expected N requirements for maximum short-term decomposition rate, based on a model assuming soil nitrogen at 0.1% and an assumed turnover rate of soil microbe population of 1.4 per year.

Source: Toogood ed. (1977)

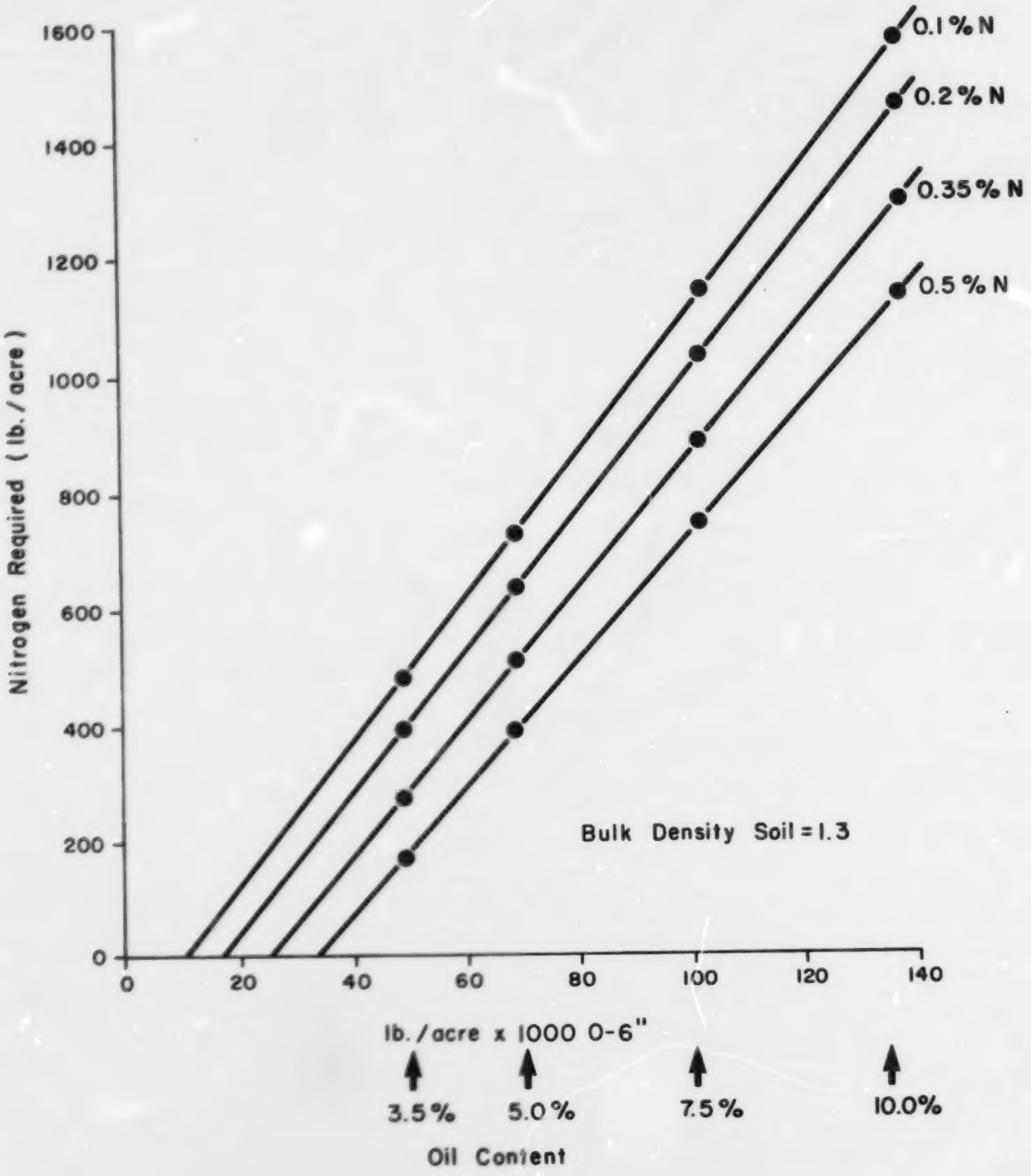

Figure 46.14. Theoretical estimates of N requirement for oil decomposition in soils of different N contents as produced by computer simulation of a model system. Assumed turnover rate of soil microbes as in Figure 46.13 and $k_{oil} = 0.693\ yr^{-1}$.

Source: Toogood ed. (1977)

Table 46.23. Effect of drainage, mixing and fertilization on germination and growth of oats, and pH, mineral N content, and oil content of a barren forest soil which had previously received an oil spill in the Swan Hills area of Alberta.

Treatment	Growth of oats		Soil Analysis		
	Germination %	Yield (g/32 ft²)	pH[a]	$NH_4 + NO_3$ nitrogen (ppm)[b]	Oil (%)[a]
Not drained					
- Nil	0	0	4.8	0	99
-NPKS[c]	0	0	4.9	1	55
-NPKS; soil mixing	0	0	5.3	0	54
-NPKS; soil mixing; and amendments[d]	0	0	6.6	0	46
Drained					
-Nil	2	1	4.5	1	107
-NPKS	2	2	4.8	25	107
-NPKS; soil mixing	80	95	4.9	56	16
-NPKS; soil mixing; and amendments	80	210	7.0	1	21

Source: Nyborg et al. (1974)

[a] Sample for pH and oil determination taken 4 months after imposition of treatments.

[b] Samples for NH_4 and NO_3 determination taken 6 weeks after imposition of treatments.

[c] N, P, K and S added at a rate of 896, 224, 224 and 90 kg/ha, respectively.

[d] Amendments consisted of: $CaCO_3$ at 26.9 T/ha; inoculation with 8.9 T/ha of a Black cultivated soil which previously had been contaminated with oil and contained a large population of oil decomposing organisms; plus an addition of micronutrients (Fe, Mn, Zn, Cu, B, Mo).

water well but good germination could be obtained by frequent watering. Plants on most treatments showed no toxicity symptoms and poor growth may have been primarily due to poor wettability of the soil.

For soils contaminated with brine spills part of the problem is that nutrients, normally made plant available through the exchange complex, have been replaced or removed by Na, which has saturated the cation exchange capacity. Thus fertilization will alleviate the Na induced nutrient deficiences and in turn enhance plant survival and growth (Table 46.17 and 46.18).

Farmyard manure is a well known conditioner for agricultural soils. Rowell and McGill (1978) reported on research to improve the productivity of agricultural land where a heavy spill had occurred 25 years previously. Although no reclamation had been attempted, most of the oil near the surface had decomposed. There were small barren areas where the soil was hydrophobic and powdery. Manure improved the aggregation of these soils and helped to correct the productivity problem. The Concawe Secretariat (1974) suggested that barnyard manure may add beneficial microbes where the soil has been sterilized by burning oil residue.

In cleanup operations, McGill (1976) suggested that straw or sawdust may be used to filter the discharge water from a site and may be useful to soak up the oil. However, if these materials are left on the site, they will tend to immobilize nitrogen. Rowell and McGill (1978) reported poor growth on straw bales used as initial growth media.

Hileman (1974) studied rehabilitation methods for land in Arkansas that was flooded with oil field brine. Poultry manure compost was applied at 13.5 t/ha and worked into the top 10 cm of soil. The pH, which was initially acidic, was improved, Na was reduced, and P and Ca were increased (Table 46.24). The author claimed that neither raw manure or sewage slude would be as effective as good quality compost because these latter materials add salts.

46.2.8 Cropping

When an oil spill occurs, destruction of the vegetation is dramatic and almost immediate. McGill et al. (1974) stated that plant

Table 46.24. The effect of poultry manure compost on a soil contaminated with oil-field brine in Arkansas.

Treatment	pH[a]	kg/ha					Conductivity[a] ECx10^3
		P	K	Ca	Na	Mg	
Brine contaminated soil	4.9	8	39	196	811	81	0.46
Brine + manure	6.2	81	45	460	56	96	0.40

Source: Adapted from Hileman (1974).
[a]1:2 soil/water ratio.

growth is reduced or eliminated by crude oil due to direct toxicity, poor aeration within the soil, poor wettability of the soil, and a low content of available nutrients due to oil decomposition. Restoration and rehabilitaion is aimed at re-establishment of a favourable environment for plant growth.

Initially restoration and rehabilitation requires successful establishment. Since oil contamination may inhibit or prevent germination as was previously noted (Chapter 46.1.1) the initial reclamation stage is to ameliorate the soil to the point where germination and revegetation can be initiated.

Cropping success gradually improves after cleanup and the oil content of the soil is reduced. The Concawe Secretariat (1974) suggested that crop production may be below normal in the first year but normal yields can be reached after two or three years. Eventually a new, higher level of productivity may actually be attained. Seed germination may be reduced in the first year. At first, shallow-rooted crops and hardy grasses should be grown.

The experiments of Toogood (1974) on a Grey [Luvisolic] soil at Breton and a Black Chernozem at Ellerslie were begun in 1968. The crops were Triticum aestivum, Avena sativa, Hordeum vulgare, Brassica sp., Linum sp., Bromus sp., Festuca rubra, Medicago sativa, Melilotus sp. cv. Altasweede, and Melilotus sp. On the Grey (Luvisolic) soil, the hay stand, three years after oil application, was assessed at 53, 73, and 98 percent of the control where the respective oil treatments were 2, 1, and 1/3 percent oil (by weight of the surface 15 cm of soil). By 1973 most evidence of the oil had disappeared. The oil disappeared more rapidly on the plots that were cultivated annually, (i.e., the annual crop plots). Germination of Triticum and Avena was never affected though initial growth at 2 percent oil was poor. Brassica was the most sensitive of the crops and failed to germinate in 1972 at the 2 percent oil rate. Hordeum and Linum were the next most sensitive. The effects of the oil disappeared more rapidly on the Black Chernozem than on the Grey (Luvisolic) soil.

In more comprehensive studies, Toogood (1977) reported on yields of crops grown on soils contaminated with light (5.54 kg/m^2),

medium (13.7 kg/m^2), or heavy (24.9 kg/m^2) oil applications, subjected to normal or intensive cultivation, and treated or not treated with fertilizers or amendments. The crop yields, represented by the yields of Hordeum vulgare on the Black Chernozemic soil at Redwater (Figure 46.11) showed that almost complete reclamation had been accomplished by 1977, five years after the oil was applied.

Yields of vegetable root crops in 1976, four years after the oil was applied, on plots that were not heavily fertilized, showed severe reductions with increasing soil contamination with oil (Table 46.25). Sensitivity appeared to vary among these crops, with Solanum tuberosum attaining best yields at the light oil treatment at both of the plot locations. Beta sp. appeared to be the most sensitive root crop.

Cropping problems on soils contaminated with particulate sulfur are caused by acidification as the elemental sulfur is oxidized. As noted by Nyborg (1974) crop tolerances to acidity vary widely. For Medicago sativa, a pH of 6 is considered to be minimum, while for Populus sp., pH 3.5 can be tolerated. Under agricultural conditions a soil at pH 4 to 4.5 can grow Avena sativa and will support such weeds as Circium arvense or Agropyron repens.

46.3 SUMMARY

Chemical disturbances reviewed include oil, oily waste, saline water, salts, and particulate sulfur.

Summer oil spills contact vegetation directly and penetrate into the soil. In winter, oil flows slowly and is absorbed by snow. In spring spills, large areas are contaminated by water movement, although dilution occurs. Oil penetration into soil can be estimated by empirical formulae. Proper cleanup is essential for effective reclamation. Flashing accounts for about 0.1% loss of oil and evaporation up to 30%.

Oil coated soils decrease in wettability. Hydraulic conductivity is usually not impaired and may be increased. Oil spills apparently have no effect on permafrost layers in the arctic, although thermal properties of soils may be affected by destruction of vegetation and darkening of the soil surface.

Table 46.25. Root crop yields in 1976 on Black Chernozem soils at two locations near Edmonton, Alberta.

Crop	Ellerslie Plots Oil Treatment				Redwater Plots Oil Treatment			
	1[a]	2	3	4	1	2	3	4
Potatoes	13.1	17.4	9.9	1.1	6.3	8.2	1.4	0.7
Carrots	20.3	17.1	2.0	0.3	34.2	17.4	3.6	0.3
Parnsips	3.7	4.6	0.7	0.02	6.0	2.8	0.2	0.1
Beets	22.6	4.6	3.2	0	14.5	0.8	0.06	0

Source: Toogood ed. (1977).

[a] (1) not treated with crude oil, or treated at (2) 5.54, (3) 13.7 or (4) 24.9 kg/m^2 in 1973.

Bacteria populations generally increase in oil contaminated soil, although an initial decrease may be noted. Fungi increases are of lesser magnitude and decreases may occur.

Oil contamination often results in plant growth reductions as a result of microbial competition for nutrients and decreased moisture infiltration and retention. Phytotoxicity of oil is restricted to the more volatile hydrocarbons, which penetrate plant tissue particularly under conditions favouring open stomata. Chlorophyll may be dissolved and translocation blocked. These volatiles are rapidly lost after a spill so that the critical period is quite short. Roots may be less sensitive to oil damage than leaves or shoots, particularly large coarse roots with thick epidermis. However, root respiration and root biomass decreased on oil contaminated soil. Seed germination is reduced by oil; seeds of fibrous rooted species are less susceptible than seeds of trees and tap-rooted species.

While active plant tissue may be destroyed, it often recovers quickly. Higher plants are most resilient (e.g., trees may recover quickly while lichen recovery may be poor or nil). Oil weakened plants are more susceptible to injury by other environmental factors.

Plant damaging ions in brine and sump fluids have been identified as Na and Cl and K respectively. Salt contaminated soils cause decreased germination, growth, and vegetative cover. Groundwater contamination may occur from organics or Cl.

Particulate sulfur causes soil acidification, lowering pH to as low as, or less than 2. Acidification is accelerated by cultivation; plants are killed and soil erosion is common.

Reclamation of chemical spills may be done using burning, chemical treatment, leaching, biodegradation, cultivation, fertilization, and cropping.

Burning can facilitate oil spill cleanup but is usually not completely effective. Fire decreases the volatile component of oil and therefore toxicity. Burning has several disadvantages:

1. fire hazard is a concern;
2. if oil penetrates deeply into soil fire is not effective.
3. heat may disperse oil further;

4. a crust often remains after burning, reducing soil aeration, moisture penetration, and seedling germination;
5. albedo may be decreased, raising temperatures and resulting in melting of permafrost in arctic soils; and
6. Burning may kill vegetation and sterilize soils, although burning when vegetation is dormant and soil is frozen or wet reduces damage.

Chemical treatment is used primarily for Na saturated soil. No salt decomposition organisms exist. Also, no chemical treatment will directly neutralize brine effects.

Sodium saturation of soils is converted to calcium saturation using $CaCl_2$, $CaCO_3$, or $CaSO_4$. The latter (gypsum) is most commonly used.

Leaching followed by liming with gypsum will move salts deeper into the soil profile and reduce the SAR of the upper 30 cm of the solum. Liming requirements increase as rooting depth of plants increases. Three years of gypsum treatment is recommended for most situations. Native calcium has been utilized to ameliorate brine soils by increasing its solubility through acidification.

Further research is needed on transport and transformation of sump fluids in soils.

Soils acidified by particulate sulfur are generally treated by liming. The amount of lime required can be calculated relatively easily. Problems arise from using strong alkalis, using $MgCO_3$, improper prediction of lime requirements, and from improper mixing of lime into the soil.

Leaching is an essential part of chemical treatment of brine and sump fluid spills. Using water alone may be as effective as leaching with chemicals in solution; however, on clay soils the exchange complex may still be saturated after all free salt is removed. Leaching with chemicals in solution is more effective than applying chemicals to the soil and then leaching with water.

Water needs for leaching can be predicted from empirical formulae. Ponding is fast, but inefficient. Trickle irrigation is slow but efficient. Leaching in fall is most efficient due to low evaporation and low water tables. Water quality is very important.

Water can be used in the treatment of oil spills to push the oil to a convenient collection point. However, the contaminated area may also be increased.

There is extensive literature on reclamation of naturally saline agricultural soils. If interpreted and used with care, available formulae (presented in the text) may be used in the treatment of brine spills to estimate salt balance, water required for leaching, water quality requirements, liming requirements, and drainage requirements. However, this approach for the reclamation of artificially salt contaminated soils is limited for the following reasons: (1) the lack of data on salt tolerance to very high salt levels over short time periods; (2) the lack of data on salt tolerance of forest species; (3) these approaches are cost effective for spatially and temporally distributed low, but not necessarily high, salt levels; and (4) equations are intended to apply to large time and space continuums.

Microbial degradation accounts for much of the decomposition of oil spills. Microbial inoculum is generally not needed, except on very sandy, acid soils or on very acid peat. A wide variety of organisms will degrade oil; however, oils vary in their biodegradability and microbe species vary in their ability to degrade oil. Bacteria are generally more effective than fungi or actinomycetes but are less effective users of acids, alcohols or ketones than fungi. Residual material left after biodegradation of oil is similar to regular soil humic matter.

Lack of N, P, and oxygen limits biodegradation, which may require 15 to 20 years in arctic environments. Microbes compete for soil nitrogen, often decreasing its availability to plants. Fertilizers are often essential to stimulate microbial decomposition and may also stimulate plant growth.

When high rates of fertilizer are required to treat oil spills, soil pH may be lowered and some plants affected. Fertilization may increase the respiration rate of oil two to five times. Nitrate nitrogen is more effective than urea or ammonium nitrogen but the latter two may persist longer. Fertilization may increase the toxic effects of oils in forested areas and may not be applicable in the far north.

Fertilization of brine spill areas is often required to replace nutrients displaced by sodium in the soil exchange complex. Since soil cover is essential to prevent erosion and chemical spill areas do not recover immediately, a sequence of vegetation cover must be selected that will tolerate verying degrees of sodicity, acidity, or oil contamination. It may not be possible to use the original crop species in the first few years after treatment.

Cultivation of oil spills breaks crusts, provides aeration, and increases volatilization. However, contaminated soil should not be buried. Normal cultivation practices are generally sufficient. Fertilization is often required as a companion treatment. The amount of fertilizer and tillage depends upon the oil content of the soil. On good quality soils under agricultural climates only three years is required to rehabilitate heavy spills.

Cultivation of salt spills is used to incorporate amendments. Tillage should be as shallow as possible. However, deep plowing may be used to bring natural amending materials into use.

In arctic regions, cultivation may cause thermoskarst conditions.

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SECTION XIV

RECOMMENDATIONS FOR FUTURE RESEARCH

47. RECOMMENDATIONS FOR FUTURE RESEARCH

The following recommendations for future research are based on the analysis of literature in the text and the experience of the authors. This section includes all research needs suggested by the available information; those needs that are currently being addressed wholly (***) or in part (*) under the Alberta reclamation research program are identified. That program is presently dealing with many of the major problem areas of concern to Alberta. As well, many of the identified research needs have undoubtedly been addressed in the post-1980 literature.

The recommendations are presented in an order of priority that is the opinion of the authors and does not necessarily reflect opinion expressed in the literature reviewed.

Priorities have been classed as "High", Medium", and "Low" and have been numerically ranked within the High and Medium classes only. Many of the low priority recommendations constitute a refinement of present knowledge of reclamation techniques, which can be achieved in short term programs, and which will provide a positive cost/benefit result to reclamation programs. Others in this category are somewhat peripheral to reclamation of physical land disturbance.

47.1 HIGH PRIORITY RESEARCH NEEDS

(***) 1. Development of a substrate quality rating system that can be applied to a wide range of spoil types, as opposed to site specific application. The rating system must consider chemical, physical, and where appropriate, biological properties, and encompass the utilization of amendments. Optimally, the rating system should have some capability to assess natural ecosystems.

(***) 2. Definition of the thickness of subsoil/topsoil treatments as well as buffer treatments (e.g. coal ash and gypsum) required to counteract salt migration from spoil into the productive rooting zone in the Plains region.

(***) 3. Improvement of the capability for long range prediction of, and restoration of water quality in reclaimed mine

sites. This should include a dynamic model of groundwater processes (including process of weathering and spoil/water interactions) following mining.

(***) 4. Determination of the optimum amounts, mixing depth, and biological stability of peat/spoil mixtures on oil sands for specific forest community types.

(***) 5. Determination of the effect of storage on the chemical, physical and biological properties of topsoil and peat.

(***) 6. Research in the Oil Sands region should concentrate on the effects of spoil and spoil amendments on plant establishment and performance.

7. Modification of standard soil analytical methodologies to interpret the unique chemical characteristics of spoils. This is particularly important for plant available nutrients and chemical imbalances.

8. Development and improvement of methodology for characterization and analyses of physical properties of spoil material.

(*) 9. Determination of optimum tree and shrub species for oil sands reclamation.

(*) 10. Development of an understanding of soil-plant nutrient cycling in reconstructed soils.

11. Determination of the optimum rates of fertilizer application for establishment of grasses and legumes on reclamation sites in Mountains and Foothills and Oil Sands regions.

12. Understanding of how stand composition of grass and grass/legume mixtures can be manipulated by number and rate of fertilizer applications.

13. Determination of the timing and periodicity of establishment and maintenance fertilizer treatments on reclamation sites in Mountains and Foothills and Oil Sands regions.

(*) 14. Determination of the longevity of topsoil versus fertilizer effects in Mountains and Foothills region.

(*) 15. Investigations of growth form, growth rate, physiological requirements and tolerance, plant-site relationships, and nutrient requirements for native trees and shrubs on reclaimed sites in the Mountains and Foothills region.

16. Establishment of shrubs into grass swards in the Oil Sands and to some extent also in the Plains regions.

(*) 17. Research on native grasses for reclamation in the Mountains and Foothills region is required. More emphasis is required on Festuca saximontana, Festuca rubra, Festuca idahoensis, Stipa columbiana, Trisetum spicatum, Calamagrostis purpurescens, Poa interior, Phleum alpinum, and Carex species.

(*) 18. Development of alternatives to fertilizer treatments (for example topsoil, peat, sewage) for reclaiming spoils, including evaluation of the interaction of fertilizer treatments with other site amendments.

47.2 MEDIUM PRIORITY RESEARCH NEEDS

1. Development of improved capabilities for prediction of chemical and physical characteristics resulting from pedogenesis of spoil. Studies should consider the short-term effects of leaching and weathering as well as long-term effects such as humification.

2. Investigations of the effects of fertilizer treatments on native, agronomic and native/agronomic grass species mixtures in Alberta (dominance of agronomic vs. native; dominance of individual species). Studies should include investigation of the sequence of natural invasion of reclaimed lands, in the interest of conversion from agronomic to native stands, or conversion from maintained to self maintained stands.

3. Determination of sampling design and sampling densities for the valid chemical characterization of spoils. This

should consider spatial variability and the prediction of direction and magnitude of change.

(*) 4. Microbial dynamics of spoils and spoil/plant relationships (including weathering, organic matter decomposition, and fertilizer symbiont relationships).

(*) 5. Investigation of the use of several grass and legume species for reclamation. Species for study include Agropyron (riparium, trachycaulum, trichophorum) for use in the Oil Sands region where published research on species use has been limited primarily to Festuca and Bromus. Other grasses worthy of study include Agropyron cristatum, Agropyron desertorum, Festuca arundinacea, Elymus giganteus, Elymus junceus, and Lolium perenne. The legumes Onobrychis and Medicago deserve attention. Investigation should include the response of agronomic grasses to interspecific competition and fertilization.

6. Determination of the best methods of collection, handling, and planting of cuttings of various promising reclamation species in Alberta.

7. Investigations of native forbs and legumes for alpine and subalpine reclamation (optimum species and cultural requirements).

8. Determination of fertility requirements of spoils and requirements for maintenance of long term fertility of soils reconstructed from spoils.

(*) 9. Development of a methodology for relating erosion potential to spoil properties in a form that can be utilized in predictive models.

(*) 10. Development and use of sediment ponds for specific purposes on mined lands, particularly in the Mountains and Foothills region.

(*) 11. Investigations of species/mulch interactions in Mountains and Foothills region and elsewhere on steep slopes.

12. Determination of how rodent and wildlife damage can be reduced or eliminated in woody plant/grass systems.

(*) 13. Definition and understanding of the interaction among bacteria, actinorhizae, and mycorrhizae symbioses (including methods for culture and application of inoculum), and the species specific relationships of mycorrhizae and actinorhizae.

(*) 14. Design of equipment for mining and reclamation. This research should be of a cooperative nature between mining and equipment manufacturing personnel.

(*) 15. Interpretation of research on sewage applied to natural and undisturbed soil situations for application to spoil situations.

16. Determination of the effect of elevation on species response to fertilizers.

17. Investigations of native and agronomic species suitability for saline spoils and Plains regions.

18. Studies of the species Dactylis glomerata as a candidate reclamation species at high elevations and in Alberta in general.

19. Evaluation of information on seeding and planting from forestry and other literature as it applies to reclamation.

47.3 LOW PRIORITY RESEARCH NEEDS

(*) 1. Investigations of Agropyron species differences and Medicago variety differences in reclamation success at high elevation.

2. Improvement of the knowledge of remote sensing image characteristics of individual plant species and plant species relationships.

3. Upgrading of multiband coverage remote sensing techniques for reclamation purposes.

4. Evaluation of the economics of remote sensing for specific situations for comparison with other survey techniques.
5. A thorough literature review to evaluate remote sensing as a reclamation tool and preparation of a handbook for application of techniques.
(*) 6. Determination and distinction of the biological and physical angles of repose for mine spoils.
7. Investigation of the N contribution of a nodulated woody plant species to spoil and plant communities.
8. Investigation of the feasibility of introducing soil mesofauna (earthworms, arthropods and small vertebrates) into spoil and their role in spoil pedogenesis.
9. Development and longevity of mechanical moisture retention treatments of plains spoils on a site specific basis.
(*) 10. Development and standardization of extraction and analytical techniques for physical and chemical properties of coal ash.
(*) 11. Determination of the fate of pathogens in sludge and effluent applied to land.
12. Determination of the optimum seeding time for Onobrychis viciifolia in Plains situations.
13. Condense the existing work of Selner and Vaartnou on Oil Sands reclamation into handbook form.
14. Investigations of methods of establishment, survival and growth, palatability, drought resistance, and salinity tolerance of woody plants in the Plains region.
15. Determination of the optimum seeding rate for various species and species mixes of grasses and legumes.
16. Determination of the cost/benefit ratios of treatments in combination with, or alternative to topsoil.
17. Site specific research is required on species - topsoil requirements.

18. Research needs related to irrigation of reclaimed sites are limited in Alberta; requirements may exist in the southern Plains region. Where considered, research needs include the effect of time of application on species performance and the interaction of time and amount of application on species performance.
19. Investigations of the production and planting of deciduous stock in small (500 cc) containers.
20. Investigation of the response of weed species to cultural treatments (irrigation, topsoiling, fertilization), in order to predict future management requirements.
21. Definition of transport mechanisms and transformation products of sump fluids in soils. This research should deal primarily with the production and transport of toxic materials following reclamation treatment, and the effects of these materials on vegetation and animals.
22. Investigation of species tolerance to various toxicities (salts, etc.).
23. Modification of equations developed for reclamation of naturally saline soils for application to reclamation of brine spills.

47.4 OTHER NEEDS

Information on total area of land disturbed by activities such as mining, energy exploration and development, and corridor construction (e.g. highways, pipelines) should be collated for the entire province on an annual basis. This would greatly facilitate reclamation planning.

SECTION XV

APPENDIX

48. LIST OF SPECIES USED IN THIS REPORT

Abies

balsamea.....balsam fir
lasiocarpa.....alpine fir, balsam fir

Acer

grandidentatum.....bigtooth maple
pseudoplatanus.....sycamore maple
negundo.....Manitoba maple, box elder, ash-leaved maple
rubra.....red maple, scarlet maple

Achillea

millefolium.....milfoil, common yarrow
ptarmica.....sneezeweed

Aegopodium

podagraria.....goutweed

Agropyron

albicans.....Montana wheatgrass
bakeri.....baker wheatgrass
cristatum.....crested wheatgrass
dastystachyum.....northern wheatgrass, critana thickspike wheatgrass
desertorum.....desert wheatgrass
elongatum.....tall wheatgrass
inerme.....beardless wheatgrass
intermedium.....intermediate wheatgrass
latiglume.....broad-glumed wheatgrass
pauciflorum.....slender wheatgrass
repens.....couchgrass, quackgrass
riparium.....streambank wheatgrass
scribneri.....spreading wheatgrass, scribner wheatgrass
sibiricum.....Siberian wheatgrass
smithii.....western wheatgrass
spicatum.....bluebunch wheatgrass
subsecundum.....awned wheatgrass, bearded wheatgrass
trachycaulum.....slender wheatgrass
trichophorum.....pubescent wheatgrass
triticeum.....annual wheat

Agrostis

alba.....redtop
canina.....brown-bent, velvet-bent
maritima.....creeping bent, carpet bent
palustris.....creeping bent
stolonifera.....redtop
tenuis.....Rhode Island bent, Colonial bent

Alnus

crispa.....green alder, Mountain alder
glutinosa.....black alder, European alder, European black alder
incana.....white alder

tenuifolia.....speckled alder, mountain alder
viridis.....green alder

Alopecurus

arundinaceus.....creeping foxtail
pratensis.....meadow foxtail

Ambrosia

psilostachya.....perennial ragweed

Amelanchier

alnifolia.....Saskatoon, serviceberry

Ammophila

breviligulata.....American beachgrass

Amorpha

canescens.....lead plant

Andropogon

gerardii.....big bluestem
hallii.....sand bluestem
scoparius.....little bluestem

Anemone

cylindrica.....thimble weed
nemorosa.....wood anemone
occidentalis.....chaliceflower
patens.....prairie-smoke

Antennaria

alpina.....alpine pussytoes
lanata.....wooly pussytoes

Anthyllis

vulneraria.....lady's-fingers

Arctagrostis

latifolia.....tall arcticgrass

Arctophila

fulva.....no common name found

Arctostaphylos

uva - ursi.....bearberry

Arenaria

rubella.....sandwort

Aristida

oligantha.....Prairie three-awn

Arnica

mollis.....Cordilleran arnica

Arrhenatherum

elatius.....tall oat-grass

Artemisia

abrotanum.....oldman wormwood
absinthium.....common wormwood
caudata.....tailed wormwood
cana.....silver sagebrush
frigida.....fringed sagewort
gnaphalodes.....Prairie sagewort
ludoviciana.....cudweed sagewort, white sage
tilesii.....Herriot's sage
tridentata.....big sagebrush
vulgaris.....mugwort wormwood

Aster

alpinus.....alpine aster
conspicuus.....snowy aster
ericoides.....many-flowered aster
pansus.....tufted white prarie aster

Astragalus

cicer .....cicer milk-vetch

Atriplex

canescens.....fourwing saltbush
nuttallii.....Nuttall's atriplex, saltbush

Avena

fatua.....wild oats
sativa.....cultivated oats

Balsamorrhiza

sagittata.....arrowleaf balsamroot

Beta

vulgaris.....beets

Betula

nigra.....red birch, river birch
pubescens.....hairy birch
pumila var. glandulifera.....swamp birch
papyrifera.....white birch, canoe birch, paper birch
verrucosa.....European white birch

Bidens

cernua.....beggars-ticks
polyepsis.....beggars-ticks

Bouteloua

curtipendula.....side-oats grama
gracilis.....blue grama

Brassica

campestris.....rapeseed
hirta.....white mustard
napus.....rapeseed
oleracoa var. accephala.....kale
rapa.....white turnip

Bromus

arvensis.....field brome
brevis.....slimleaf brome
ciliatus.....fringed brome
inermis.....smooth brome, awnless brome
japonicus.....Japanese chess
marginatus.....mountain brome
pumpellianus.....northern awnless brome
tectorum.....downy chess, cheatgrass

Buchloe

dactyloides.....buffalograss

Calamagrostis

canadensis.....marsh reed grass,bluejoint
inexpansa.....northern reed grass
purpurescens.....purple reed grass

Calamovilfa

longifolia.....sand grass, Prarie sandreed

Calluna

vulgaris.....heather

Campanula

rotundifolia.....harebell, bluebell

Caragana

arborescens.....common caragana, Siberian peatree, Siberian peashrub

Cardamine

bellidifolia.....alpine bittercress
pratensis.....cuckoo-flower

Carduus

nutans.....musk-thistle

Carex

aquatalis.....water sedge
bigelowii.....stiff sedge

paysonia.....sedge
nigricans.....blackening sedge
spectabilis.....sedge
stans.....sedge

Cassiope

mertensiana.....western mountain-heather

Castilleja

rhexifolia.....painted cup

Ceanothus

martinni.....martin ceanothus
prostratus.....squaw-carpet
velutinus.....snowbrush ceanothus

Celmisia

lyallii.....daisy

Cenchrus

ciliaris.....buffel grass

Centaurea

nigra.....knapweed, Spanish-buttons

Cerastium

alpinum.....alpine chickweed

Cercocarpus

ledifolius.....curlleaf mahogany
montanus.....birchleaf mahogany

Ceratoides

lanata.....winterfat

Chamaenerion

angustifolium.....fireweed (see Epilobium)

Chionchloa

macra.....A New Zealand grass
pallens.....A New Zealand grass

Chrysanthemum

leucanthemum.....ox-eye-daisy, white daisy

Chrysothamnus

nauseosus.....rubber rabbitbrush
nauseosus var. consimilis.....alkali rubber rabbitbrush
nauseosus var. graveolens.....green rubber rabbitbrush

Cirsium

arvense.....Canadian thistle
vulgare.....bull-thistle, common thistle

Clematis

ligusticifolia.....western virginsbower

Cochlearia

officinalis.....scurvygrass

Colobanthus.....no common name found

Colutea

arborescens.....common bladdersenna

Commandra

pallida.....bastard toad-flax

Comptonia

peregrina.....sweet-fern

Cornus

canadensis.....bunchberry
stolonifera.....red-osier dogwood

Coronilla

varia.....field crown-vetch

Cotoneaster

interessima.....cotoneaster

Cowania

mexicana.....Stansbury cliffrose

Crataegus

monogyna.....English hawthorn
oxyacantha.....English hawthorn
rivularis.....hawthorn

Cynodon

dactylon.....Bermuda grass

Cystisus

scoparius.....Scotch broom

Dactylis

glomerata.....orchard grass

Danthonia

intermedia.....timber oat-grass
parryi.....Parry oat-grass

Deschampsia

atropurpurea.....mountain hairgrass
beringensis.....hairgrass
caespitosa.....tufted hairgrass
flexuosa.....common hairgrass

Descurainia

sophoides.....northern flixweed

Digitalis

purpurea.....foxglove

Distichlis

spicata var. stricata.....inland saltgrass
stricata.....inland saltgrass

Draba

bellii.....draba

Dryas

drummondii.....yellow mountain-avens
integrifolia.....white mountain-avens
octopetala.....mountain dryad

Dryopteris

felix-mas.....male fern

Dupontia

fisheri.....tundra grass

Echinacea

angustifolia.....black samson

Echinochloa

frumentacea.....Japanese millet, billion-dollar grass
muricata.....barnyard grass

Elaeagnus

angustifolia.....Russian olive
commutata.....wolf-willow, silverberry
umbellata.....oleaster

Elymus

angustus.....Altai wild rye
canadensis.....Canada wild rye
cinereus.....basin wild rye, giant wild rye
condensatus.....giant wild rye
giganteus.....mammoth wild rye
glacus.....smooth wild rye
innovatus.....hairy wild rye
junceus.....Russian wild rye
triticoides.....beardless wildrye

Empetrum

nigrum ssp. hermaphroditum.....black crowberry, curlewberry

Epilobium

alpinum.....alpine willow weed
angustifolium.....fire weed
parviflorum.....willow weed

Equisetum

arvense.....common horsetail

Eragrostis

curvula.....weeping lovegrass

Erigeron

caespitosus.....tufted fleabane

Eriophorum

chamissonis.....cotton grass
vaginatum.....sheathed cotton-grass

Euonymus

europaeus.....European spindle-tree

Euphrasia

officinalis.....eyebright

Eurotia

lanata.....winterfat

Fallugia

paradoxa.....Apache-plume

Festuca

arundinacea.....tall fescue, reed fescue,
elatior.....meadow fescue
idahoensis.....Idahoe fescue, blue bunch fescue

ovina.....sheep fescue
ovina var. brachyphylla.....alpine fescue
ovina var. duriuscula.....hard fescue
rubra.....red fescue, creeping red fescue, Ky 31 fescue
rubra var. commutata.....Chewings fescue
saximontana.....sheep fescue, saximontana fescue
scabrella.....rough fescue

Forestira

neomexicana.....New Mexico olive

Forsythia

ovata.....forsythia, goldenbell

Fragaria

vesca.....woodland strawberry, sow-teat strawberry

Fraxinus

americana.....white ash
excelsior.....European ash
pennsylvanica.....green ash
pennsylvanica var. lanceolata.....green ash

Galium

boreale.....northern bedstraw
saxatile.....leather-bedstraw
verum.....yellow bedstraw

Geum

triflorum.....three-flowered avens, old man's whiskers, purple avens, prairie smoke

Ginkgo

biloboa.....ginkgo

Glycine

max.....soy-bean

Grindelia

perennis.....curlycup-gumweed

Gutierrezia

sarothrae.....broomweed, matchbrush

Halimodendron

halodendron.....salttree

Hedysarum

alpinum.....American hedysarum
borealis var. utahensis.....Utah sweetvetch
mackenzii.....northern hedysarum
sulphurescens.....yellow hedysarum

Helianthus

annuus.....annual sunflower
rigidus.....stiff sunflower

Helictotrichon

hookeri.....Hooker's oat grass

Heracleum

sphondylium.....heltrot, hogweed

Hesperochloa

kingii.....western grass

Heuchera

richardsonii.....alumroot

Hieracium

perpropinquum.....hawkweed
pilosella.....mouse-ear
umbellatum.....Canada hawkweed

Hierochloe

alpina.....holy grass

Hilaria

jamesii.....galleta

Hippophoae

rhamnoides.....sea buckthorn

Holcus

lanatus.....velvet-grass

Hordeum

jubatum.....wild barley, foxtail barley
vulgare.....barley

Ilex

aquifolium.....holly

Juglans

nigra.....black walnut

Juncus

drummondi.....Drummond's rush

Juniperus

horizontalis.....creeping juniper
monosperma.....one-seed juniper
scopulorum.....Rocky Mountain juniper, red cedar
virginiana.....eastern juniper

Kobresia

myosuroides.....bog-sedge

Kochia

prostrata.....prostrate kochia
scoparia.....summercyress

Koeleria

cristata.....junegrass

Lactuca.....lettuce

Larix

laricina.....tamarack, larch

Lathyrus

ochroleucus.....white pea vetch, peavine, cream-coloured vetchling
sylvestris.....flatpea
venosus.....wild peavine

Ledum

groenlandicum.....Labrador tea
palustre ssp. decumbens.....Labrador tea

Lespedeza

cuneata.....sericea lespedeza

Ligustrum

vulgare.....privet, prim

Linaria

vulgaris.....butter-and-eggs

Linum

lewisii.....Lewis flax,wild blue flax

Lolium

multiflorum.....annual rye, Italian rye
perenne.....prennial rye grass

Lonicera

halimifolium.....matrimonyvine
tatarica.....tatatian honeysuckle
tatarica cv. rosea.....rose tatarian honeysuckle

Lotus

corniculatus .....bird's-foot trefoil
pedunculatus.....trefoil

Luetkea

pectinata.....luetkea, meadow spiraea

Lunaria

dalmatica.....honesty

Lupinus

argenteus.....silvery lupine

Luzula

confusa.....northern wood-rush
glabrata.....smooth wood-rush
spicata.....spike wood-rush

Lycopersicon

esculentum.....tomato

Lysimachia

terrestris.....yellow or swamp-loosestrife

Medicago

sativa.....alfalfa (also M. media)

Melilotus

alba.....white sweet-clover
officinalis.....yellow sweet-clover

Myrica

cerifera.....waymyrtle
pennsylvanica.....bayberry

Nothofagus

solandri var. cliffortioides.....southern beech

Onobrychis

sativa.....common sainfoin
vicilfolia.....Eski sainfoin, common sainfoin

Oryzopsis

hymenoides.....Indian rice grass

Oxyria

digyna.....mountain-sorrel

Oxytropis

campestris.....late yellow locoweed

Panicum

amarulum.....costal panicgrass
clandestinum.....deertongue
virgatum.....switch grass

Papaver

radicatum.....Arctic poppy

Parthenocissus

quinquefolia.....Virginia creeper

Paspalum

nostatum var. saurae.....Pensacola bahia grass

Penstemon

fruticosus.....bush penstemon
lemtus.....beard-tongue
newberryi.....Newberry penstemon
procerus.....slender blue beard-tongue

Peraphyllum

ramosissimum.....squaw apple

Petalostemum

purpureum.....purple prairie clover

Phacelia

sericea.....silky scorpion-weed

Phalaris

arundinacea.....reed canary grass

Phaseolus.....beans

Phippsia

algida.....snowgrass

Phleum

alpinum.....Alpine timothy, mountain timothy
pratense.....timothy

Picea

engelmanni.....Engelmann spruce, white spruce
excelsa.....Norway spruce
glauca.....white spruce
mariana.....black spruce
sitchensis.....tideland spruce, sitka spruce

Pinus

albicaulis.....white bark pine
banksiana.....jack pine, gray pine
caribaea.....slash pine
contorta.....scrub pine

contorta var. latifolia.....lodgepole pine
flexilis.....limber pine
mugo var. mughus.....mugo pine
ponderosa.....ponderosa pine, yellow pine, bull pine
resinosa.....red pine, Norway pine
taeda.....loblolly pine, old field pine
strobus.....Eastern white pine, white pine
sylvestris.....Scotch pine
thunbergii.....Japanese black pine
virginiana.....Virginia pine, Jersey pine, scrub pine

Pisum

sativum.....garden pea

Plantago

lanceolata.....ribgrass, ripplegrass

Platanus

occidentalis.....American sycamore, sycamore, button-wood

Poa

ampla.....big blue grass
alpina.....alpine blue grass
compressa.....Canada blue grass
glauca.....glaucous speargrass
glaucantha.....bluegrass
interior.....wood blue grass
lanata.....hairy blue grass
pratensis.....Kentucky blue grass
trivialis.....rough-stalked blue grass, rough blue grass

Polygonum

bistortoides.....American bistort
cuspidatum var. compacta.....Japanese knotweed
pennsylvanicum.....pinkweed

Populus

alba.....silver poplar
angustifolia.....narrowleaf cottonwood
balsamifera.....balsam poplar
canadensis var. grandifolia.....Carolina poplar
deltoides.....eastern cottonwood

gradidentata.....large-toothed aspen
nigra var. italica.....lombardy poplar
petrowskiana.....Russian poplar
robusta.....poplar (a cross)
sargentii.....plains cottonwood, western cottonwood
tremula.....European aspen
tremuloides.....trembling aspen, quaking aspen, aspen

Potentilla

arguta.....tall cinquefoil
canadensis.....Canadian cinquefoil
fruticosa.....bush cinquefoil
hyparctica.....cinquefoil

Prosopsis.....mesquite

Prunus

americana.....American plum, wild plum
besseyi.....Bessey cherry
fasciculata.....peach tree
maritima.....beach plum
padus.....mayday
pennsylvanica.....pin cherry, wild red cherry, bird cherry
serotina.....wild black cherry, rum cherry
tomentosa.....Nanking cherry
virginiana.....black-fruited chokecherry, chokecherry

Puccinellia

airoides.....Nuttall alkali-grass
borealis.....Alaskan alkali-grass
nuttalliana.....Nuttall alkali-grass
ruthlaliana.....alkali grass

Pseudotsuga

menziesii.....Douglas fir

Purshia

glandulosa.....desert bitterbrush
tridentata.....antelope bitterbrush

Quercus

gambelii.....Gambell oak
imbricaria.....shingle oak, laurel oak
palustris.....pin oak, swamp Spanish oak
prinus.....chestnut oak, basket oak, cow oak
rubra.....northern red oak, red oak, Spanish oak

Ranunculus

sabinei.....buttercup

Ratibida

columnifera.....prairie coneflower

Reseda

luteola.....Dyer's rocket

Rhus

aromatica var. trilobata.....skunkbush
copallina.....flameleaf sumac
glabra.....smooth sumac
trilobata.....skunkbush sumac

Ribes

aureum.....golden currant

Robinia

fertilis.....Arnot bristly locust
hispida.....bristly locust, rose acacia, bristly black locust
pseudoacacia.....black locust, acacia, yellow locust

Rosa

acicularis.....prickly rose
arkansana.....Arkansas rose
hansoni.....Hanson hedgerose
rugosa.....rugosa rose
woodsii.....Wood's rose

Rubus

chamaemorus.....baked-apple, cloudberry
fruticosus.....cutleaf blackberry

Rumex

acetosella.....sheep-sorrel, common sorrel

Salsola

kali.....Russian thistle, common saltwort
kali var. tenuifolia.....Russian thistle

Salix

acutifolia.....acute willow
alba.....white willow
alba var. vitellina.....golden willow
britzensis.....willow
damascus.....damson-leafed willow
fragilis.....brittle willow
fragilis var. basfordiana redher.....Basford willow
humilus.....gray willow
nigra.....black willow
nivalis.....snow willow
pentandra.....laurel willow
purpurea.....purple osier, basket willow

Sambucus

cerulea.....blueberry, elder, blue elderberry

Sarcobatus

vermiculatus.....black greasewood

Sarothamnus

scoparius.....broom

Sassafras.....sassafras

Saxifraga

caespitosa.....tufted saxifrage
cernua.....nodding saxifrage
oppositifolia.....red-flowered saxifrage

Schizachne

purpurascens.....purple oat grass

Schizachyrium

scoparium.....little bluestem

Scirpus

americanus.....three-square bulrush

Secale

cereale.....rye, winter rye, common spring rye, fall rye, cereal rye
montanum.....mountain rye

Senecio

congestus.....marsh fleabane
jacobaea.....stinking willie
viscosus.....stinking groundsel

Sheperdia

argentea.....buffaloberry, silver buffaloberry
canadensis.....Canada buffaloberry

Sibbaldia

procumbens.....sibbaldia

Sisyrinchium

montanum.....common blue-eyed grass

Sitanion

hystrix.....squirreltail

Solanum

tuberosum.....potatoe

Solidago

missouriensis.....Missouri goldenrod, low goldenrod

Sorbus

aucuparia.....rowan tree

Sorghum

sudanense.....sudan grass
vulgare.....sorghum

Sporobolus

airoides.....alkali sacaton
cryptandrus.....sand dropseed

Stellaria

monantha.....chickweed

Stipa

columbiana.....Columbia needle grass
comata.....needle-and-thread
richardsonii.....Richardson needle grass
spartea var. curtiseta.....western porcupine grass
viridula.....common green needle grass

Stiporyzopsis

caduca.....Mandan ricegrass

Symphoricarpos

albus.....snowberry
oreophilus.....Mountain snowberry
vaccinioides.....whortleaf snowberry

Syringa

vulgaris.....common lilac

Tanacetum

vulgare.....common tansy

Taraxacum

officinale.....common dandelion

Thermopsis

montana.....Montana thermopsis
rhombifolia.....buffalo bean, golden bean

Tragopogon

dubius.....yellow goat's-beard

Trifolium

aureum.....yellow clover
hybridum.....alsike clover
pratense.....red clover

procumbens.....low hop-clover
repens.....white clover
subterraneum.....subclover

Trisetum

spicatum.....spike trisetum

Triticum

aestivum.....winter wheat, common wheat, spring wheat

Tussilago

farfara.....coltsfoot

Typha

latifolia.....common cattail

Ulex

europaeus.....furze, gorse

Ulmus

americana.....white elm
glabra.....wych elm
pumila.....Siberian elm, Manchurian elm, Chinese elm

Vaccinium

membranaceum.....bilberry
myrtilloides.....blueberry
uliginosum.....blueberry
vitis-idaea.....lingonberry, bog cranberry
vitis-idaea ssp. minus.....bearberry

Valeriana

sitchensis.....mountain heliotrope

Viburnum

opulus.....highbush cranberry

Vicia

cracca.....tufted vetch, crown vetch

Vitis

riparia.....river-bank grape, frost-grape

Zea

mais.....corn

POOR

QUALITY

ORIGINAL